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HIGHWAY RESEARCH RECORD

Number 420

Vehicle Characteristics, Restraint Systems, and Inspection Programs

4 reports

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Vehicle Characteristics, Restraint Systems, and Inspection Programs

4 reports
prepared for the
51st Annual Meeting

Subject Areas

51	Highway Safety
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53	Traffic Control and Operations

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Washington, D.C. 1972

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ISBN 0-309-02092-1
Library of Congress Catalog Card No. 72-12132
Price: $2.00
Available from
Highway Research Board
National Academy of Sciences
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

CONTENTS

FOREWORD

The papers in the RECORD cover a variety of subject areas, but the focal point of each paper is the vehicle.

The first paper was prepared at the request of the Committee on Vehicle Characteristics. In it, Seger and Brink trace significant changes in the physical and performance characteristics of automobiles for the model years 1960 through 1970. Cars became smaller, lighter, and less powerful from 1960 through 1962. The trend, however, reversed at that time. A consistent reduction during the years in overall height and center of gravity in combination with wider tread achieved important improvements in vehicle stability. From 1962 through 1970, there was also a small downward trend in vehicle economy.

Grush, Henson, and Ritterling review the effectiveness of 15 occupant-restraint systems. The effectiveness value for each restraint system was determined for a range of impact speeds and frontal impact directions to form the effectiveness matrices used in the study. The authors conclude that a complete lap-belt system used in air-bag-equipped passenger cars would have saved 17,900 lives in 1969. A discussion by Warner challenges some of the conclusions of the paper. Among the conclusions challenged is one indicating that cost-effectiveness would be greater from increased use of active-restraint systems than of passive-restraint systems. The discussant refers to one recent occupant motivation study that concluded that only gradual, limited success will be seen in attempts to encourage use of active restraints.

Kennedy discusses the problem of damage-producing shocks and vibrations in the shipment of cargo by intermodal containers. The first 2 areas approached and discussed are shock classification of highway vehicles and classification of cargo-restraint systems. A jointly sponsored project is described to develop a shock index equation based on actual static and dynamic measurements.

In the final paper, Sherman reports on a survey of driver opinions toward periodic motor vehicle inspection. The survey was conducted in Ann Arbor, Michigan; Washington, D. C.; and Cincinnati, Ohio. The results of the survey indicate that those drivers who responded were overwhelmingly in favor of motor vehicle inspection.

TRENDS OF VEHICLE DIMENSIONS AND PERFORMANCE CHARACTERISTICS FROM 1960 THROUGH 1970

E. E. Seger and R. S. Brink, General Motors Proving Ground, Milford, Michigan

The past decade was unique because of the many styling and other engineering innovations, a proliferation of new models, and the emergence of the 2-door hardtop as the most popular model. Of equal importance and interest were the dramatic increases in available horsepower ratings and customer demand for equipment items that add significantly to the safety, comfort, and convenience of driving. Important changes were made in the physical dimensions and performance characteristics. Our survey reveals that cars became smaller, lighter, and less powerful from 1960 through 1962. These trends, however, were reversed after that time. A consistent reduction during the years in overall height and center of gravity and a widening of tread achieved important improvements in vehicle stability. The average eye height above the ground decreased 1.5 in. to 43.9 in. The minimum eye height decreased 3.0 in. to 39.3 in. From 1962 through 1970, there was a small downward trend in fuel economy. Important advances in vehicle performance contributed to more efficient use of highways.

•ONE OF the functions of the engineering staff at the General Motors Technical Center is the annual compilation of vehicle and body dimensions covering all U.S. domestic cars in the industry as reported in passenger car specifications of the American Manufacturers Association. This project is performed as a corporation service for the several GM engineering groups. These compilations constitute the source of the data used in developing trends relative to vehicle and body dimensions for the model years 1960 through 1970. The General Motors Proving Ground annually conducts an extensive engineering test audit of vehicles that GM and competitive companies have in current production. This program has existed since the beginning of GM Proving Ground activities in 1924. The data used in developing the trends for 1960 through 1970 with respect to vehicle economy and performance characteristics were extracted from this body of information.

The emphasis in this paper is directed to the trends from 1960 through 1970 because changes were made in test procedures and methods early in the past decade that do not permit direct comparisons with the trend studies published previously. The reader of this paper should bear in mind that the compiled domestic car registrations for 1970 indicate that vehicles 5 years of age or under represented 51 percent of the cars in use and those 10 years of age or under represented 88 percent. These facts should be considered in evaluations of the distribution of the trends among the vehicle population.

NUMBER OF BODY STYLES USED TO DETERMINE AVERAGE DIMENSIONS

An indication of the number of body styles available each year can be had from the number of dimensions used each year to determine the average dimensions. These numbers should not be interpreted to be the same as the number of car models available each year because models were grouped in various ways by the various manufacturers for stating body dimensions. For example, some companies made groupings for stating

Sponsored by Committee on Vehicle Characteristics.

seat height that were different from those used in determining eye heights because those companies specified differing heights for manual seats, power seats, and bucket seats, each of which may have been the same for more than one model. The number of body styles used for stating dimensions increased from about 125 at the beginning of the decade to more than 300 at the middle of the decade (Fig. 1).

OVERALL LENGTH

From 1960 through 1962, average overall length decreased 10 in. from 213 to 203 in. (Fig. 2). Most passenger cars became shorter, but the greatest contribution was made by the first generation of the smaller type of cars. After 1962, overall length gradually increased as succeeding generations of new designs were introduced into production. By 1970, the average value had reached 210 in. The maximum and minimum values increased after 1962. The new generation of small cars will probably effect some reduction in average and minimum values. Overall length consists of 3 components: front overhang, wheelbase, and rear overhang. Analysis of each component is required for a proper understanding of the trends in dimensional characteristics.

Front Overhang

Front overhang length decreased from 1960 through 1962 when cars generally became smaller and shorter (Fig. 3). In 1963, however, an increase was initiated that continued through 1970. The rate of increase accelerated after 1967 because of the trend to long hood and short rear-deck styling, and the average value exceeded the 1960 level after 1965. The 1970 value was about 39 in. In the later years, both maximum and minimum values were also noticeably greater, 44 and 30 in.

Wheelbase

Wheelbase, the major component of overall length, became shorter on the average from 1960 through 1963 (Fig. 4). This was primarily a direct result of the introduction of several new lines of small economy-sized cars. The average wheelbase length, however, remained stable after that time. Although some of the larger models showed significant increases, the stabilization after 1963 at 118 in. was effected by the proliferation of the small and intermediate models. Accordingly, the range of values (97 to 133 in.) was wider in 1970 than it was in 1960. 1970 wheelbase lengths with respect to car-size groups were as follows:

Size	Avg	Range
Small	108	97 to 111
Intermediate	114	112 to 117
Full	123	117 to 133

Rear Overhang

Rear overhang, the rear component of overall length, became noticeably shorter from 1960 through 1962 when several new lines of small cars were introduced (Fig. 5). The average overhang increased from 1962 through 1965 (when some lines of small cars became of intermediate size) and then remained stable through 1968. The trend to a shorter overhang in the later years reflected a trend toward short rear-deck styling. Although the maximum overhang remained stable at about 62.5 in. after 1963, the minimum value decreased noticeably in 1965 and again in 1970 to a new low of 38 in.

ANGLE OF APPROACH

The length of the front overhang is one of the important design elements that determine the angle of approach. As the overhang increases, for example, the approach angle tends to decrease. The average approach angle increased considerably from 1960 through 1962 because of the shorter front overhang designed into most cars (Fig. 6). Significant decreases in the angle values are noted in 1963 and again during the 3 years

Figure 1. Body styles.

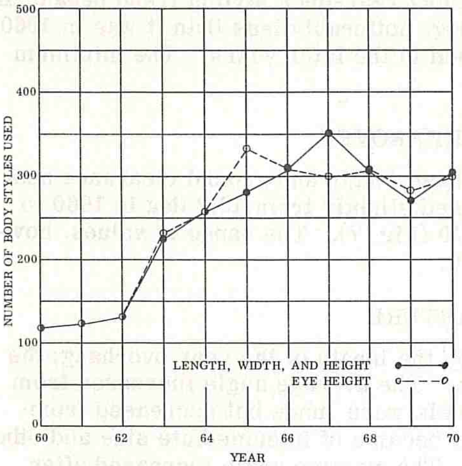


Figure 2. Overall length.

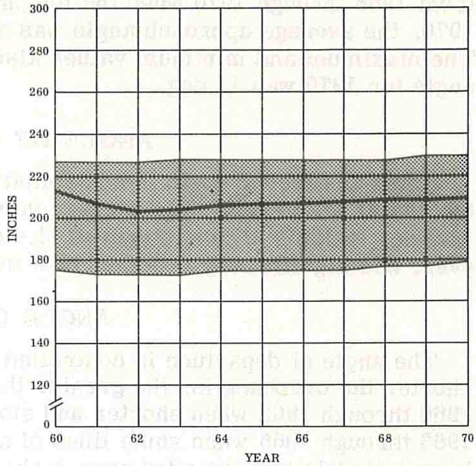


Figure 3. Front overhang.

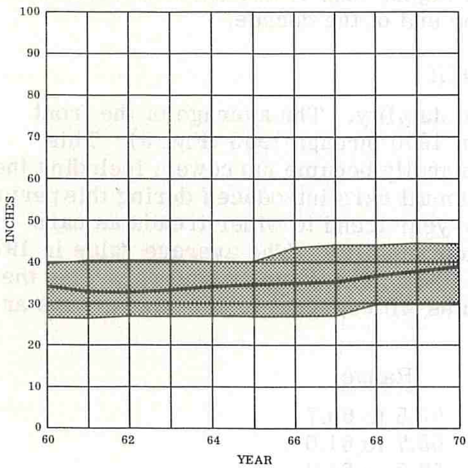


Figure 4. Wheel base.

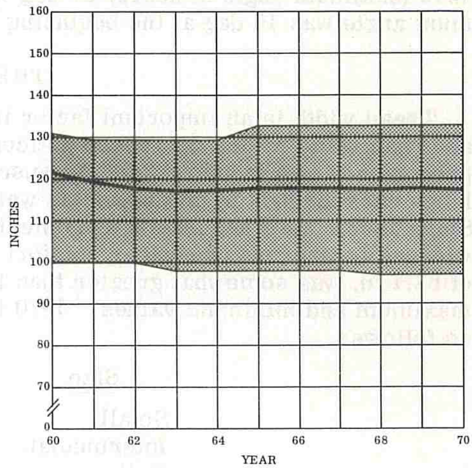


Figure 5. Rear overhang.

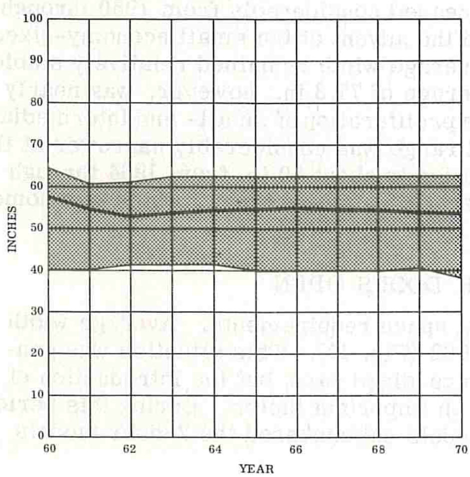
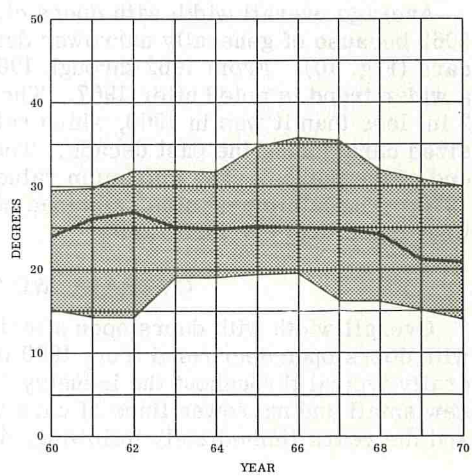


Figure 6. Angle of approach.



from 1968 through 1970 when the long hood and short rear-deck styling trend began. In 1970, the average approach angle was about 21 deg, noticeably less than it was in 1960. The maximum and minimum values also decreased in the later years. The minimum angle for 1970 was 14 deg.

ANGLE OF RAMP BREAKOVER

Ramp-breakover angle is controlled by wheelbase length and ground clearance near the center of the car. The average value increased slightly from 12.2 deg in 1960 to 12.9 deg in 1967, then declined to 11.4 deg in 1970 (Fig. 7). The range of values, however, was significantly wider in 1970 than in 1960.

ANGLE OF DEPARTURE

The angle of departure is controlled largely by the length of the rear overhang; the shorter the overhang is, the greater the angle is. The average angle increased from 1960 through 1962 when shorter and smaller models were made but decreased from 1963 through 1966 when some lines of small cars became of intermediate size and other larger models had extended rear decks (Fig. 8). The average angle increased after 1966 because of the shorter rear overhang that is characteristic of the short rear-deck styling trend. The range of angle values widened considerably in the past 3 years. The 1970 maximum angle of nearly 27 deg was much higher than it was in 1960. The minimum angle was 10 deg at the beginning and at the end of the decade.

TREAD WIDTH

Tread width is an important factor in vehicle stability. The average of the front and rear tread widths decreased noticeably from 1960 through 1963 (Fig. 9). This phenomenon was industry-wide because cars generally became narrower, including the large cars already in production as well as the small cars introduced during this period. Since 1963, there has been a consistent year-by-year trend to wider treads as cars widened to improve passenger comfort and vehicle stability. The average value in 1970 of 61.1 in. was somewhat greater than it was in 1960. The same is true regarding the maximum and minimum values. 1970 tread widths with respect to car-size groups are as follows:

Size	Avg	Range
Small	58.1	55.5 to 60.7
Intermediate	59.7	58.7 to 61.0
Full	62.8	59.7 to 64.3

OVERALL WIDTH WITH DOORS CLOSED

Average overall width with doors closed decreased considerably from 1960 through 1962 because of generally narrower designs and the advent of the small economy-sized cars (Fig. 10). From 1962 through 1967, the average width remained relatively stable; a wider trend is noted after 1967. The 1970 average of 77.3 in., however, was nearly 2 in. less than it was in 1960, which reflects the proliferation of small- and intermediate-sized cars during the past decade. The overall range was considerably narrower at the end of the period. The maximum value was limited to about 80 in. from 1964 through 1970. The minimum value remained stable after 1965 at about 69 in., which was somewhat more than the 1960 value.

OVERALL WIDTH WITH DOORS OPEN

Overall width with doors open affects parking space requirements. Average width with doors open decreased from 1960 through 1962 (Fig. 11). This situation was generally typical throughout the industry for the large-sized cars, but the introduction of new small and narrower lines of cars was also an important factor. During this period and the years immediately following, 4-door models outnumbered the 2-door models

with wider doors. Since 1962, the average width increased consistently and was significantly greater in 1970, at 154 in., than in 1960. This circumstance reflects not only a general widening trend for all models but also, and more important, the increased proliferation of 2-door models, which outnumbered the 4-door models in the more recent production years. The maximum width increased significantly in 1967 with the introduction of some large-sized specialty 2-door hardtops but remained stable after that time at 175 in. The minimum value was somewhat lower from 1968 through 1970 than it was in 1960 because of the appearance of some new small types of 4-door models.

WALL-TO-WALL TURNING DIAMETER

Turning diameter is not included in the AMA passenger car dimensions; therefore, these curves are based on tests of selected cars. Wall-to-wall turning diameter was influenced considerably by wheelbase and changes in length of the front overhang. The trends are closely related. Average turning diameter decreased from 1960 through 1963 as the result of the shorter front overhang designed into the established lines of cars as well as many the new shorter and smaller size cars (Fig. 12). Turning diameter increased from 1963 to 1970 as front overhang became longer for the large cars and as small cars lengthened to intermediate size. The average 1970 turning diameter value was about 45.5 ft, which was somewhat more than it was in 1960. The range of 1970 values (51.5 to 39.5 ft) was narrower, and the minimum was noticeably larger.

OVERALL HEIGHT

The styling trend during the past decade and since the early years of the industry has been toward reduced overall height of cars (Fig. 13). This trend has produced during the years a notable lowering of eye height above the ground and improved quality of vehicle stability. (These subjects will be discussed later.) A previous trend study showed that overall height is not correlated closely with the other commonly understood attributes of smallness. So it is that the range and the average of values were not influenced significantly in the early years of the decade by the advent of small cars. Only a modest reduction of 1.3 in. was achieved during the entire 10-year period, which resulted primarily from styling innovations for the specialty types of 2-door hardtops. During the 25-year period preceding the past 10 years, average overall height had been reduced 12 in. This evidence suggests that the average value is leveling out below 54 in. The maximum values did not change appreciably in the past 10-year period. The minimum values, however, decreased about 4 in. and reached a new low of 47.3 in. The factors that appear to put a practical limit on further decreases in minimum overall height include adequate interior headroom, acceptable seat height above the floor, body structural requirements, and satisfactory ground clearance.

EYE HEIGHT

One of the notable effects of reduction in overall height is the lowering of the eye height above the ground. The body-dimensioning procedures did not provide an eye-height measurement. The dimensions from which eye heights could be estimated changed twice during the past decade. The 3 methods for estimating the eye heights used in this report are as follows: 1960 to 1961, free A-point to ground minus A-point depressed depth plus 29.1 in.; 1962 to 1964, H-point to ground plus 25.0 in.; and 1965 to 1970, body zero to ground (front) plus body zero to ground (rear) divided by 2 plus H-point to body zero plus 25.0 in. These changes in methods do not appear to have affected the final results. The average value for 1969 and 1970 was about 44 in. (Fig. 14). During the 1960-1970 period, average eye height decreased 1.5 in., which correlates well with the reduction in overall height. The maximum eye height decreased less than 1 in., but the minimum decreased 3 in. to 39.3 in.

CENTER-OF-GRAVITY HEIGHT

The center-of-gravity data used for the trend chart and for this discussion are limited to the representative cars selected for this test. The trend study is shown for the

Figure 7. Angle of ramp breakover.

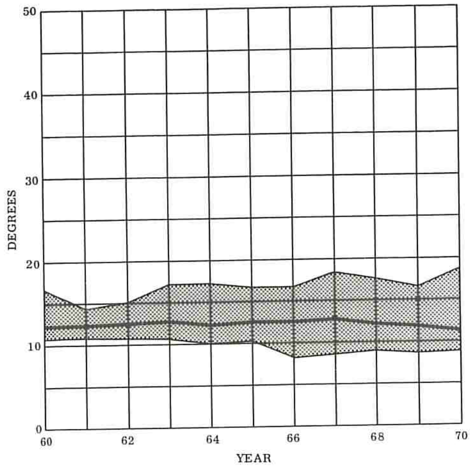


Figure 8. Angle of departure.

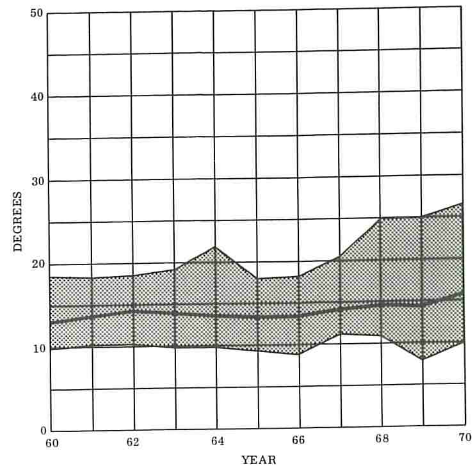


Figure 9. Tread width.

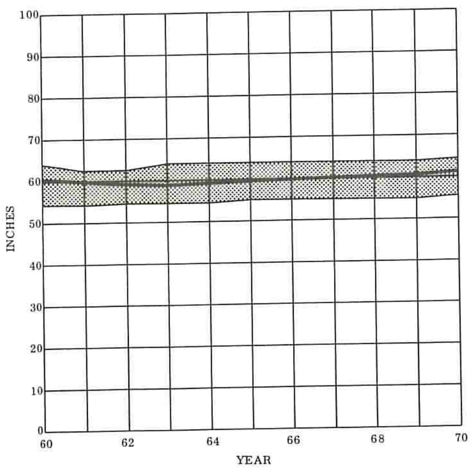


Figure 10. Overall width—doors closed.

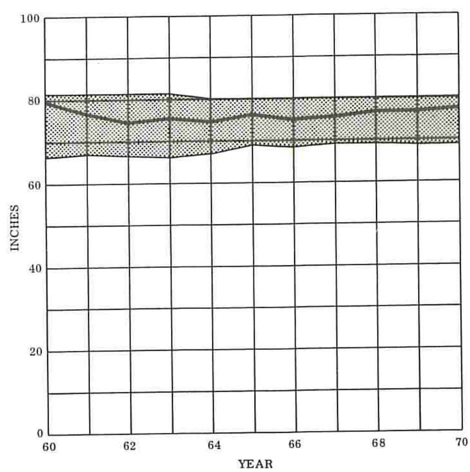


Figure 11. Overall width—doors open.

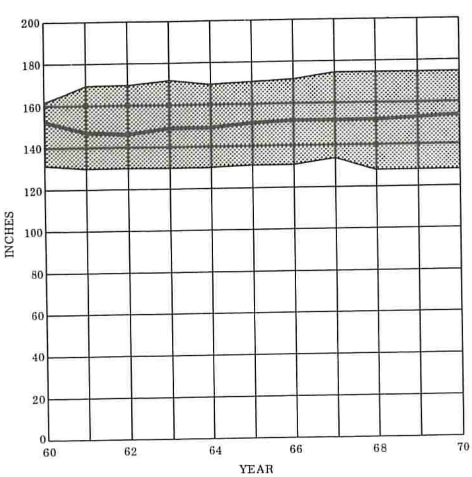
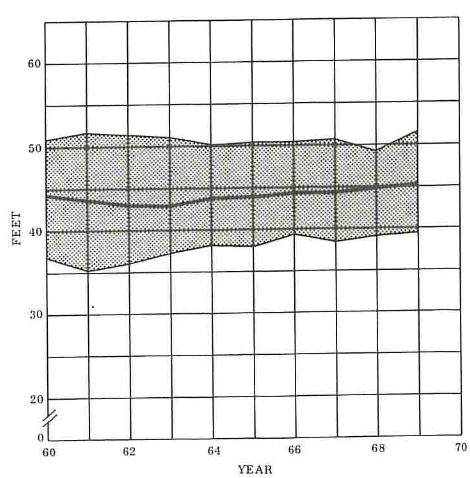


Figure 12. Turning diameter.



1960-1968 period (Fig. 15). The trend is toward lower overall height; the average height of the center of gravity was lowered about 5 in. between 1936 and 1968 and about 1.5 in. between 1960 and 1968. Although the lower center-of-gravity height was achieved largely through a reduction in overall height, other design changes contributed to the reduction. This is evidenced by the lower maximum, average, and minimum values. The reduction accomplished during the years contributed significantly to improved vehicle stability.

STABILITY FACTOR

The stability factor T/(2H), where T is the average of front and rear tread and H is the height of center of gravity, is a measure of the resistance of a car to overturning. From 1960 through 1968, the average stability factor of the representative cars improved from 1.4 to 1.5 (Fig. 16); in the preceding 25-year period, it had improved from 1.2 to 1.4. This substantial improvement was achieved through lowering the center of gravity in combination with widening the tread.

AVERAGE ENGINE DISPLACEMENT, TORQUE, AND POWER

A survey of engine sizes, based on the average of the announced engines, reveals dramatic changes during the past 20 years (Fig. 17). The displacement and advertised torque were the highest ever in 1970. The average of advertised horsepower, however, reached an all-time maximum of 260 in 1958, climaxing a period of intensive development of the modern high-compression V-8 engine introduced in 1948. An important decline in engine size developed during the 1959-1962 period, primarily from the increased use of the lower powered 6-cylinder engines prominently featured with the introduction of smaller economy cars. A sharply increasing trend was resumed during the period from 1964 through 1966. Changes in engine size, torque, and power were relatively small during the past 4 years. During the 10-year period, 1960 through 1970, there were increases in the numbers and ratings of higher horsepower engine options, particularly for the small, intermediate, and low-priced full-sized cars.

ENGINE TORQUE-TO-DISPLACEMENT RATIO AND POWER-TO-DISPLACEMENT RATIO

The trend of the averages of the ratios of torque to displacement and the ratios of power to displacement illustrates aspects of engine development. The ratio of torque to displacement can be increased by increasing compression ratio, reducing friction, and improving efficiency in other ways. The ratio of maximum power to displacement can be increased by these methods and by using larger carburetors, valves, and exhaust systems to improve breathing; by changing valve and ignition timing; and by building the engine to withstand operation at higher speeds. The ratios increased rapidly from 1950 through 1958 (Fig. 18). The power-to-displacement ratio increased more rapidly than the torque-to-displacement ratio. Both sets of ratios fell from 1959 through 1963 when small cars were introduced.

DISTRIBUTION OF ENGINE DISPLACEMENT

A survey of the distribution of displacements of engines produced in the 1962 and the 1970 model years reveals interesting trends (6). The cars equipped with engines of as much as 200 $in.^3$ displacement diminished from 32 percent of the cars produced in 1962 to less than 4 percent in 1970 (Fig. 19). Those with displacements ranging from 201 to 250 declined from 18 to 9 percent. Six-cylinder engines had displacements of 250 $in.^3$ or less. For 1970, the domestic automobile-makers produced no engines with displacements in the 251 to 300 $in.^3$ range, which as recently as the 1967 model year had accounted for 29 percent of all domestic passenger-car assemblies. Cars equipped with displacements in the 301 to 350 $in.^3$ range increased from 7 percent of production in 1962 to 45 percent in 1970. Those with displacements in the 351 to 400 $in.^3$ range increased slightly from 23 to 24 percent. Those with displacements larger than 400 $in.^3$ increased from 5 to 18 percent.

Figure 13. Overall height.

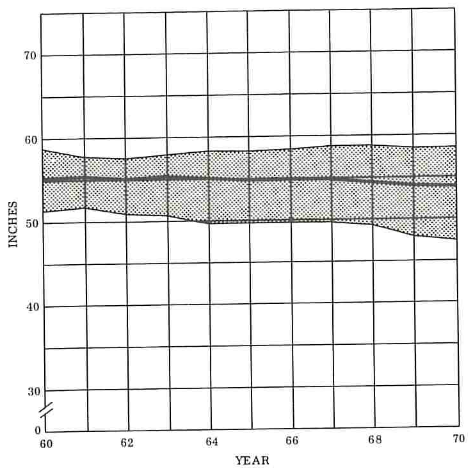


Figure 14. Eye height.

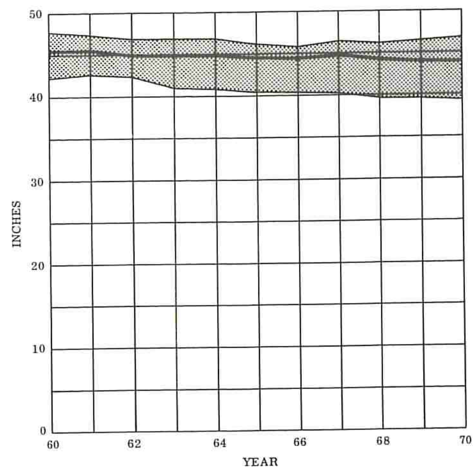


Figure 15. Center-of-gravity height.

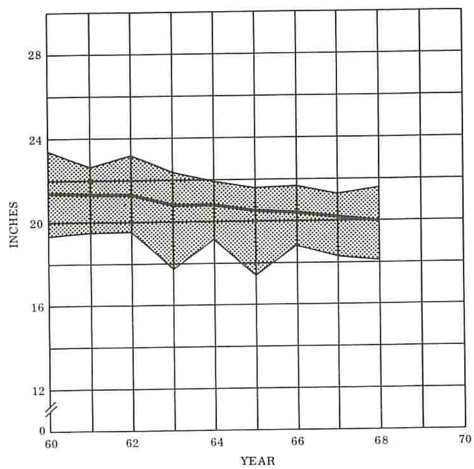


Figure 16. Stability factor.

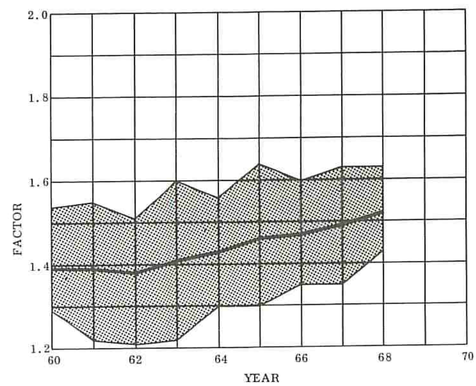


Figure 17. Engine size.

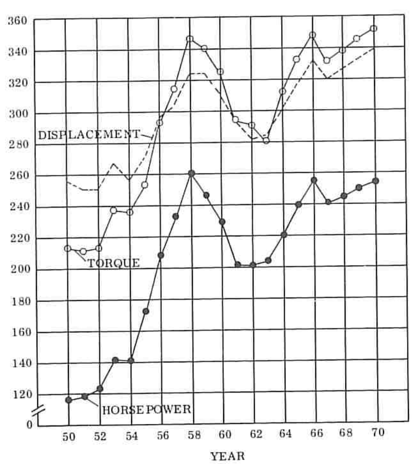
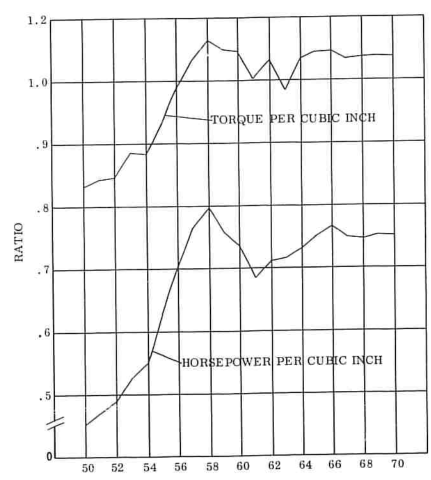


Figure 18. Displacement ratios.



ADVERTISED BRAKE HORSEPOWER

As stated in the introduction, the data selected to develop the trends of vehicle performance and fuel economy were extracted from the body of information accumulated from the annual engineering audits conducted at the GM Proving Ground. These audits are made by skilled test crews on models selected from the current engineering and distribution fleet. This group of cars is generally representative of production from year to year but is not all-inclusive for reasons of economics. Accordingly, the availability and the selection of models for the audit are somewhat restricted and arbitrary. Our survey of the average engine brake horsepower ratings reveals that the trends during the past 10 years of those selected for the Proving Ground audit parallel closely the trends of those available in the industry (Fig. 20). The Proving Ground level, however, is consistently higher than that of the industry average. This is because the lower powered 6-cylinder engines had a relatively small representation. It is also true that some of the highest performance options available were not tested. The Proving Ground audit, however, is representative of most of the cars in use because those equipped with the minimum and maximum horsepower ratings rank relatively low in percentage of the total number of cars sold.

POWER EQUIPMENT INSTALLED

Advertised brake horsepower is not, in itself, an absolute measurement of vehicle performance. It is well known, for example, that power is lost in transmission through the power train. Significant developments have occurred in past years that involve the proliferation of optional equipment items that not only contribute to the safety, comfort, and convenience of driving but also may affect performance and fuel economy. Automatic transmission installations increased from 72 percent in 1960 to 91 percent in 1970 (Fig. 21). Power steering use went up from 39 to 85 percent. Power brakes increased from 26 to 59 percent. Air conditioner installations rose from 5 to 60 percent. The greatly expanded installations of V-8 engines—from 57 percent in 1960 to 88 percent in 1970—and increased horsepower served to restore the power losses involved in the use of the equipment listed above and to provide additional power reserve for emergency performance requirements.

OBSERVED WEIGHT

Observations of vehicle weight are included in the Proving Ground audits because weight is related to the performance and economy results. The data used here were observed on the representative cars selected for performance and economy tests. The average weight was reduced considerably from 1960 through 1962 when cars generally became smaller and, therefore, lighter (Fig. 22). After 1962, they became heavier because of size increases, greater use of heavier V-8 engines, and expanded customer demand for optional equipment. The average weights for 1966 through 1970 were not much different from those for 1960. The maximum values after 1966 were lower than those in 1960, but the minimum values were somewhat higher. The weight increases from 1962 through 1966 must be included among the factors that partially nullified the potential gains from increased advertised engine horsepower ratings previously described.

BRAKES

Brake test procedures changed during the 10-year period. New tests were added. The methods of summarizing test results changed. Therefore, it would be difficult to produce a trend chart. Brake system features and the year they were available are given in Table 1. The modern automobile achieves effective deceleration rates under normal conditions with moderate pedal force, which may be as low as 50 lb or less with power booster assist that is now installed on 54 percent of production. Drivers today have no difficulty in developing deceleration rates close to 1.0 g on dry pavements when the brakes have been adequately maintained. The industry-wide adoption of automatic brake shoe adjusters during the past decade has been a practical benefit in this regard.

Figure 19. Engine displacement.

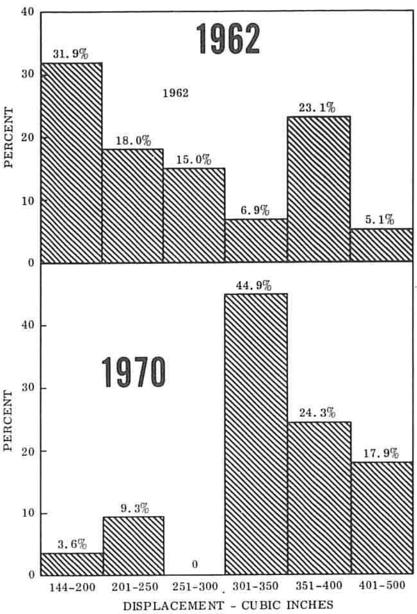


Figure 20. Brake horsepower.

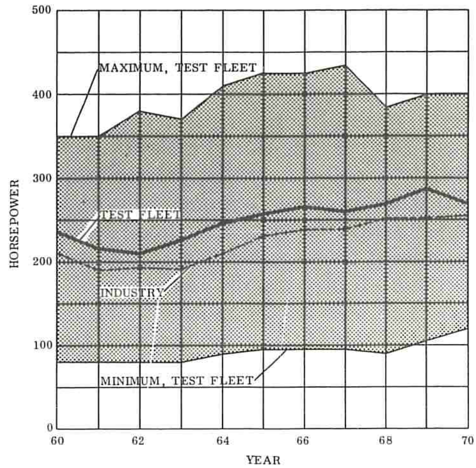


Figure 21. Power equipment.

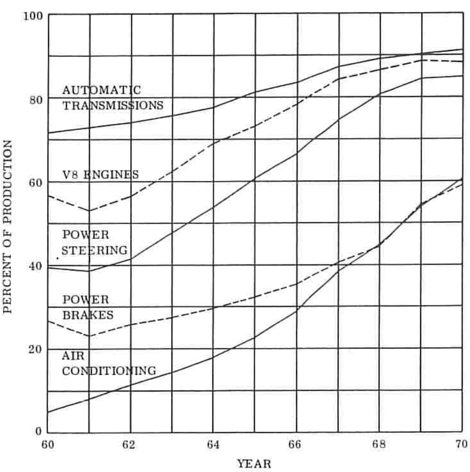


Figure 22. Weight.

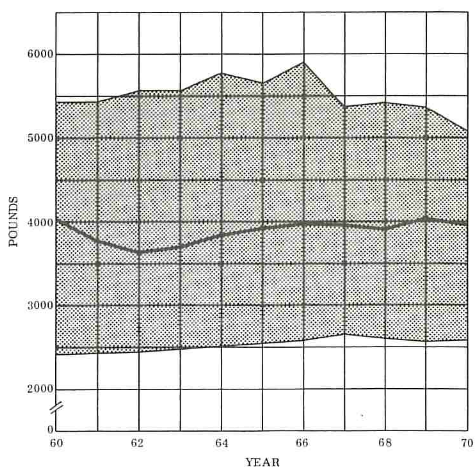


Table 1. Break features.

Feature	Availability 1960	Availability 1970	Benefits
Automatic brake shoe adjusters	Few	Universal	Maintain brake effectiveness till linings are worn out
Dual-master cylinder and divided system	None	Mandatory	All 4 brakes are not apt to fail at same time
Disk brakes on front wheels	None	Standard with booster on some heavier cars; optional with booster on most other cars	Diminish effects of heat and water
Controlled brakes on rear wheels	None	Standard on 1 luxury car; optional on a few other luxury cars	Prevent wheel lockup during emergency stops and, thus, provide better control and reduce tire damage

Wet pavements, however, have presented, and continue to present, a serious highway safety problem. Generally speaking, the maximum friction reaction of a wet pavement is less than that of a dry pavement, and all too frequently it is very much less. The condition is aggravated as the pavement becomes progressively polished under traffic. Some progress in highway improvement has developed through past research on the effect of aggregates and other surface treatments on the control of slipperiness of pavements. Continued improvement in this direction will be dependent on how well the research results are actually applied to reducing the slippery conditions.

50-MPH FUEL ECONOMY

The level fuel economy test is conducted on a large number of selected cars. The vehicle moves at a constant speed of 50 mph on a level, paved road surface. The factors that affect the test results include engine efficiency, power train losses, and wind and rolling resistance. The inertial effects of car weight and rotating components are not among the factors that influence the results. Level fuel economy for the average test car improved from 1960 through 1962 but decreased in 1963 and again in 1964 (Fig. 23). Substantial increases are noted in 1965 and 1967. After 1967, economy decreased to the 1970 value of 19.0 mpg, only 0.4 mpg below the 1960 average.

CITY FUEL ECONOMY

The city fuel economy test is conducted on a schedule that simulates city driving under normal traffic and operating conditions. The Proving Ground has used this test in its present form since 1960. The test results are influenced by engine efficiency, power train losses, wind and rolling resistance, inertial effects of vehicle weight and rotating parts during starting and accelerating operations, and power losses deriving from the requirements of energy-consuming optional equipment items. City fuel economy for the average test car improved slightly in 1962 and 1967, but the dominant trend is a year-by-year decrease after 1962 (Fig. 24). The 1970 value of 14.4 mpg is about 1.1 mpg lower than the 1960 value.

HIGHWAY FUEL ECONOMY

During 1960, the Proving Ground developed a more severe highway fuel economy test schedule that simulates driving on expressways and other types of roads commonly in use under modern traffic and operating conditions. The Proving Ground has used this test in its present form since the beginning of the 1961 model year. The test results are influenced by the same elements as those involved in the city fuel economy test, but to a different degree. Highway fuel economy for the average test car decreased from 1962 through 1965 (Fig. 25). Some improvement is noted for 1967. The 1970 value of 15.4 mpg is about 1.3 mpg lower than the 1961 value.

HIGHWAY CRUISING RANGE

Cruising range is defined as the mileage that a car will operate from a full tank of fuel. It is, therefore, by definition a function of highway fuel economy in miles per gallon and of the tank capacity in gallons. The cruising range for the average car increased year-by-year from 1960 through 1967 and again in 1969 (Fig. 26). The overall gain was from 310 miles in 1961 to 340 miles in 1969. The cruising range improvement was obviously achieved by the use of larger tanks. A 20 percent increase in capacity was responsible for a 10 percent increase in cruising range.

TIME TO ACCELERATE FROM 0 TO 60 MPH

The trends relating to engine brake horsepower ratings during the past decade were responsible for important improvements in vehicle performance capabilities. Observations of acceleration time in seconds from 0 to 60 mph, either shifting through the gears or being in drive range, provide a yardstick for comparisons from year to year. This test was run on a large number of selected cars. Our survey reveals a dramatic

improvement for the poorest performing test cars from 1960 through 1964 and again in 1969 (Fig. 27). The time was reduced from 32.5 to 18.9 sec, an improvement of 42 percent. The time for the average test car decreased from 14.2 to 11.5 sec, a 19 percent improvement. The best performing test cars registered a reduction from 8.9 to 6.6 sec, a 26 percent improvement.

PASSING SIGHT DISTANCE FROM 30 MPH

Important improvement was also achieved in passing sight distance as a direct result of the better performance capabilities previously described. The Proving Ground conducted such tests from 30 and 50 mph on a more limited selection of representative cars for the model years from 1963 through 1969. Passing sight distance from 30 mph represents the driver's mental judgment of the distance required for a passing maneuver on a 2-lane road to avoid interference with a vehicle approaching from the opposite direction. For test purposes, it is defined as the distance required for a vehicle to pass a truck, 50 ft long and moving at 30 mph, from a point 50 ft behind the truck to a point in the right lane 100 ft ahead of the truck so that there is no interference with the oncoming vehicle moving at 65 mph. Passing sight distance tests at 30 mph during the years reveal that performance improvements achieved a major reduction in the distance required for the passing maneuver and a major increase in the safety factor (Fig. 28). The distance was reduced from 2,100 to under 1,700 ft for the poorest performing test car and from 1,550 to 1,350 ft for the average test car.

PASSING SIGHT DISTANCE FROM 50 MPH

The procedure for tests of passing sight distance from 50 mph and from 30 mph is the same except that, at the start of the former test, the test vehicle and the truck are traveling at 50 mph. Tests from 50 mph likewise indicated major improvement. The distance was reduced from 2,740 to 2,490 ft for the poorest performing test car and from 2,090 to 1,880 ft for the average test car. The improvements described above may be described in other terms for emphasis. The exposure time to traffic interference at 30 mph was reduced from 9.7 to 8.1 sec for the average test car; the 50-mph test revealed a reduction from 11.2 to 9.9 sec. The poorest performing test cars achieved a reduction from 13.7 to 10.7 sec at 30 mph and a reduction from 16.0 to 13.6 sec at 50 mph.

SUMMARY

During the decade from 1960 through 1970, the average passenger-car length, weight, and power first decreased until 1962 and then increased (Table 2). The average length was 3 in. shorter in 1970 than in 1960, and the average weight was about the same in 1970 as in 1960; but the average power was 14 percent more in 1970 than in 1960. The use of power-consuming equipment increased greatly during the decade. These factors resulted in a reduction in average fuel economy of the cars tested by about 7 percent and an increase in average performance so that the average time to accelerate from to 60 mph was reduced about 19 percent to 11.5 sec. The minimum acceleration time for any car tested was 8.9 sec in 1960 and 6.6 sec in 1970. During the second quarter of the decade, the number of body styles more than doubled. The overall width of passenger cars was limited to 80 in. after 1964. The average overall width with doors open changed little, but the maximum widths increased from 162 to 175 in. As a result of changed styling, the average front overhang was increased by about 5 in. and the rear overhang was reduced by about 5 in. The average wheelbase was reduced 3.7 in. The average angle of approach decreased to 20.9 deg, and the average angle of departure increased to 15.8 deg; but the minimum angle of departure changed little from 10 deg. The minimum ramp-breakover angle decreased from 10.7 to 8.9 deg. Car heights became lower. The average eye height was reduced from 45.4 to 43.9 in. The minimum eye height decreased from 42.3 to 39.3 in. The extrapolated average center-of-gravity height of the cars tested went down from 21.4 to 19.6 in., resulting in a 12 percent improvement of the stability factor.

Figure 23. 50-mph fuel use.

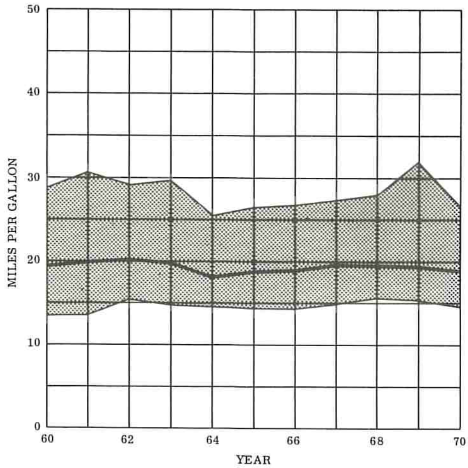


Figure 24. City fuel use.

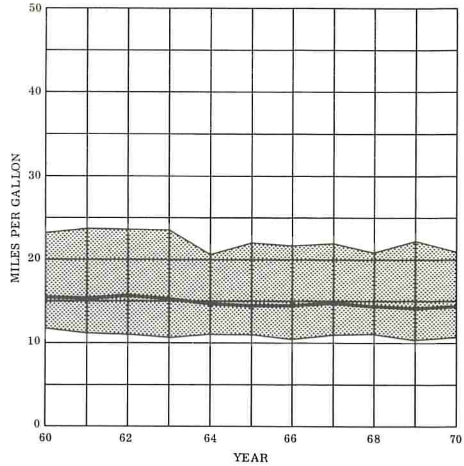


Figure 25. Highway fuel use.

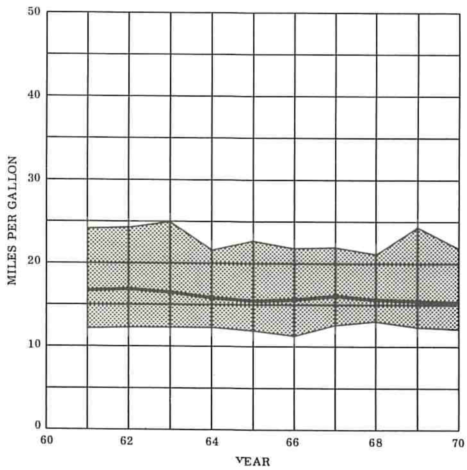


Figure 26. Cruising range.

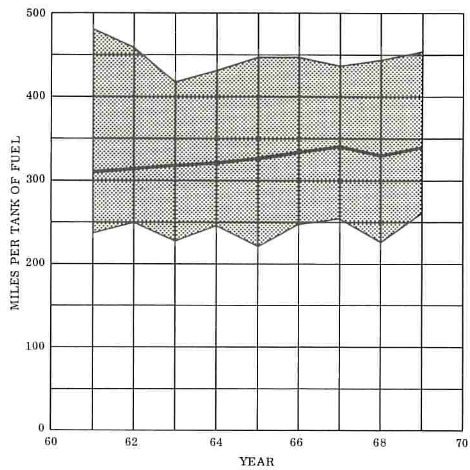


Figure 27. Acceleration to 60 mph.

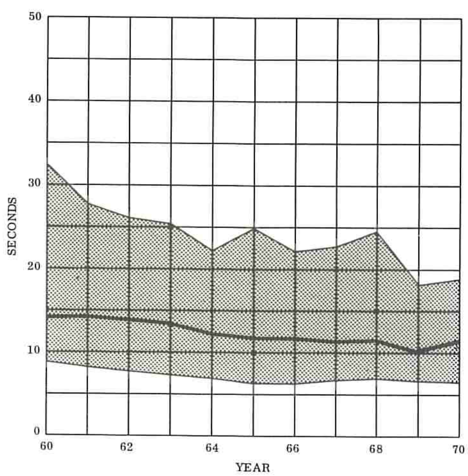


Figure 28. Passing sight distance—30 mph.

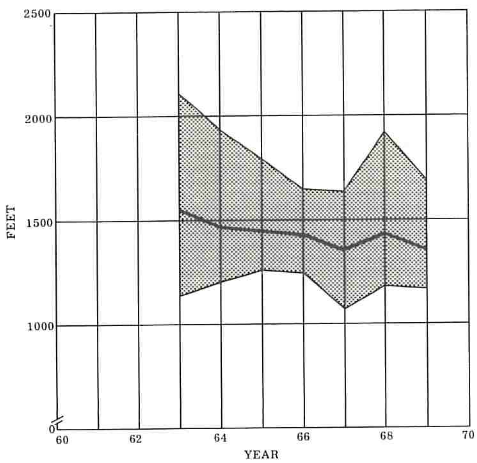


Figure 29. Passing sight distance—50 mph.

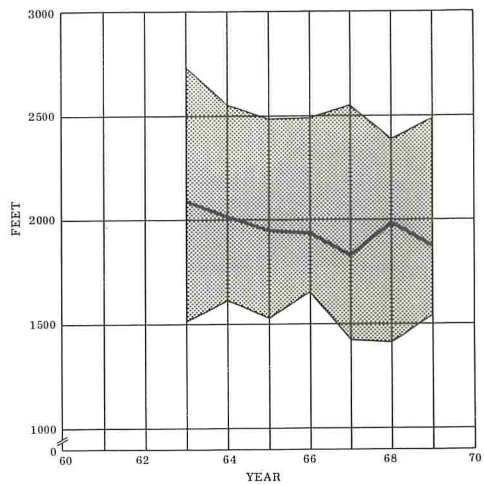


Table 2. Summary.

Item	1960	1962	1967	1970	Change (percent)
Number of body styles used to determine avg dimensions	118	132	352	305	+158
Avg overall length, in.	213	203	208	210	-1
Avg front overhang, in.	34	32	35	39	+15
Avg wheelbase, in.	121	118	118	118	-2
Avg rear overhang, in.	58	53	55	53	-9
Avg angle of approach, deg	23.9	26.9	24.9	20.9	-13
Angle of ramp breakover, deg					
Avg	12.2	12.5	12.9	11.4	-7
Min	10.7	10.8	8.6	8.9	-17
Avg angle of departure, deg	13.0	14.2	14.1	15.8	+22
Avg tread width, in.	60.5	59.1	60.1	60.9	+1
Avg overall width, with doors closed, in.	79.1	74.7	75.4	77.3	-2
Overall width, with doors open, in.					
Avg	152	146	152	154	+1
Max	162	170	175	175	+8
Avg wall-to-wall turning diameter, ft	44	43	44	46[a]	+2[a]
Avg overall height, in.	55.2	55.0	54.9	53.9	-2
Eye height, in.					
Avg	45.4	44.8	44.7	43.9	-1
Min	42.3	42.3	40.2	39.3	-7
Avg center-of-gravity height, in.	21.4	21.3	20.2	19.6[a]	-8[a]
Avg stability factor	1.39	1.38	1.49	1.56[a]	+12[a]
Avg engine displacement, $in.^3$	311	281	320	338	+9
Avg engine torque, ft-lb	325	291	331	351	+8
Avg engine horsepower	236	211	261	269	+14
Avg observed weight, lb	4,007	3,626	3,953	3,966	-1
Avg city fuel economy, mpg	15.5	15.7	14.7	14.4	-7
Avg highway fuel economy, mpg	16.7[a]	16.9	16.1	15.4	-8[a]
Time to accelerate from 0 to 60 mph, sec					
Avg	14.2	14.0	11.5	11.5	-19
Max	32.5	26.2	22.8	18.9	-42
Min	8.5	7.8	6.8	6.6	-26

[a]Extrapolated.

ACKNOWLEDGMENT

This survey was made and this paper was prepared at the request of the HRB Committee on Vehicle Characteristics. The purpose of the project is to continue through 1970 the trend data studies initiated in 1958 and updated in 1960 and 1962 (1, 2, 3, 4, 5).

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RESTRAINT-SYSTEM EFFECTIVENESS

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•IN THIS study, 3 passenger-car, occupant-restraint systems are compared as to their potential effectiveness in saving lives. The systems studied include both existing restraints, such as lap belts and shoulder harnesses, and proposed restraints, such as air bags. The potential number of lives that could be saved each year through the universal installation and use of each restraint system is calculated, and the estimates are then compared. An analysis of different systems employing the same benefit criterion and the same basic assumptions should enhance confidence in the comparative, if not the absolute, nature of conclusions about the relative effectiveness of the systems.

For each of the restraint systems studied, it was assumed that the car was equipped with an advanced steering column incorporating improved energy-dissipating characteristics. The lap-belt system consisted of a lap belt for each occupant. The shoulder-harness system was the one currently installed in passenger cars—a lap belt for each occupant with a shoulder harness in addition for the driver and right-front passenger. The third system evaluated was the air-bag system that consisted of a dynamic air bag plus a lap belt for each occupant. This system was evaluated both with and without each occupant using his lap belt. The air bags simulated in this study exhibit occupant-protection characteristics that to our knowledge are not attainable with currently developed air-bag systems. The near-term development of a system with such properties is considered feasible, however.

METHOD

Two broad tasks were undertaken to obtain the lives-saved estimates. One of the tasks involved mathematical modeling of each occupant-restraint and vehicle system in order to establish potential occupant head and chest decelerations in each of a number of narrowly categorized crash situations. Human-tolerance formulations were then used to convert these decelerations into values reflecting the ability of the restraint to save lives in each given crash situation.

The second major effort in the study was an examination of traffic accident records to determine the relative frequency of fatalities occurring in each crash situation. Two major sources of accident data were used. Total motor vehicle accident fatality data were drawn from the annual report of the National Safety Council (NSC). Distribution of fatalities by type of accident was developed from data provided by the Automotive Crash Injury Research (ACIR) program of the Cornell Aeronautical Laboratory.

Distribution of Fatalities

Motor vehicle fatalities can be categorized in a number of ways; among these is classification by placement of the fatality, e.g., truck or car occupant or pedestrian. The distribution of the 56,400 fatalities reported by NSC for 1969 is given in the tabulation. About a fifth of the fatalities (10,700) were not occupants of motor vehicles; included are pedestrians and bicyclists. Among the occupants, about a fifth were in vehicles other than passenger cars; those 8,600 fatalities were primarily truck occupants and motorcyclists. The remaining 37,100 fatalities, constituting about two-thirds of 1969 motor vehicle deaths, were occupants of passenger cars. This study is limited,

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because of the nature of the safety systems being considered, strictly to these passenger-car occupants.

Category	Number	Percent
Vehicle occupant	45,700	81
Truck	8,600	15
Passenger car	37,100	66
Pedestrian	10,700	19
Total	56,400	100

Passenger-car occupant fatalities can be classified further according to the type of impact experienced by the vehicle. Perhaps the most important impact consideration, in terms of occupant kinematics, is whether the vehicle rolled over. Among non-roll-overs, a single impact designation means that the vehicle in which the fatality occurred (fatality vehicle) collided with exactly 1 other object (which may be another vehicle); the multiple impact category includes fatality vehicles that collided with more than one object. An accident is classified as a principal roll-over when the fatality vehicle overturns without striking any other substantial object. Finally, a collision roll-over designates an accident in which the fatality vehicle collided with some object in addition to overturning.

A distribution of fatalities among these categories is as follows:

Category	Number	Percent
Non-roll-over	1,208	73.2
Single impact	934	56.6
Multiple impact	274	16.6
Roll-over	441	26.8
Principal	327	19.9
Collision	114	6.9
Total	1,649	100.0

The source for this distribution was the accident data bank maintained by the ACIR. That file consists of accident records on more than 50,000 rural, injury-producing accidents. Only the 23,000 records concerning passenger cars of model year 1960 or later were considered for use in the study so that the sample selected would more closely reflect current design level. Among the completely unrestrained occupants in this sample of vehicles, 1,649 fatalities were found, and those fatalities constitute the sample distributed by vehicle impact type. Safety-system effectiveness was determined separately for each of those impact types.

Single-Impact Effectiveness

Because most fatalities are found in the single-impact category, it seems appropriate to concentrate most of the technique description on this impact type. The life-saving benefit analysis was initiated by developing a measure that might be considered as an index of effectiveness; this measure was an estimate of the proportion of fatalities in a given accident situation that would be eliminated through occupant use of a certain restraint system. An example may make this concept of an effectiveness factor more clear.

Consider, for example, an accident situation of striking an abutment at 40 mph. Because our defined criterion is fatality reduction, our interest in this situation is only in the occupants who were killed. Suppose that all the occupants who were killed in such crashes in 1 year are counted. The question is, How many of those occupants would survive if we could repeat all the crashes with all the occupants furnished with, say, air bags? The ratio of the number saved to the original number killed represents

an index of the effectiveness of the particular restraint in the given crash situation. With a different restraint system, the effectiveness factor for this accident situation may be different. In addition, varying one of the parameters determining the accident situation would lead to a separate effectiveness factor determination.

A number of variables were used to identify the accident situation for each fatality. One of these was the seated position of the occupant. Six different seated position values were used, corresponding to the 6 normal occupant locations within the vehicle. A second factor used to describe the accident situation was the impact direction applied to the fatality vehicle. The 12 o'clock positions were used as values for this descriptor, with 12 o'clock representing a direct frontal collision. The third measure used in describing the accident situation was the impact severity, measured in terms of vehicle speed into a fixed barrier. The possible barrier speeds were partitioned into 6 ranges in a manner discussed below.

Now that the parameters indicative of the accident situation have been defined, effectiveness of each restraint within each seated position by impact direction by impact severity category can be evaluated. With 6 seated positions, 12 impact directions, and 6 impact severity levels, there are potentially $6 \times 12 \times 6 = 432$ tabular cells for which restraint-effectiveness factors could be determined. In this study, potential life-saving benefits were determined only for the 108 cells associated with frontal (11, 12, and 1 o'clock) impacts. Because most impact dynamics research, both empirical and theoretical, has been conducted with frontal impacts, comparatively little is known about dynamics in side and rear impacts, particularly when restraints are involved. The purpose of this study was to evaluate restraint systems; therefore, we feel it was justified to limit the calculations to those conditions in which the restraints would be significantly operative, the frontal impacts.

Head and Chest Decelerations

For each restraint, an effectiveness factor associated with each accident situation cell was developed. The effectiveness evaluations were based on occupant head and chest decelerations obtained from the application of computer models simulating the physical dynamics of the crash.

The Computer Simulation of the Automobile Crash Victim(1), developed at the Cornell Aeronautical Laboratory, was used for all simulations except the air bag. This is an 11-deg-of-freedom planar model of an occupant and a vehicle interior during a frontal collision. Because the Cornell model does not currently include a dynamic air-bag simulation, another model developed at Ford Motor Company especially for air-bag simulation was used. That model considers the air bag as functionally analogous to a piston, with the energy of an impacting upper torso dissipated by compressing the gas in the bag and forcing the compressed gas through an exit orifice. Tests have shown that chest decelerations are the limiting factor in predicting survival for air-bag-restrained occupants; therefore, only chest loads are measured in this simulation.

The 3 systems studied consist of a number of basic restraint components. The peak head decelerations that were obtained for each component at each speed are shown in Figure 1, and chest decelerations are shown in Figure 2.

It was more convenient to use the peak deceleration level rather than some average or "effective" level, although the latter may be more appropriate. This use of peak values seemed justified because all the measured deceleration pulses tended toward a skewed-bell shape, yielding a relatively constant relation between peak and effective deceleration values. This idealized condition is not always found in real crashes, where the waves are more irregular and sometimes have thin "spikes"—of doubtful significance—superimposed on the basic pulse shape.

Small, medium, and large occupants were simulated for each restraint component, corresponding to the 5th percentile female, 50th percentile male, and 95th percentile male. From decelerations measured for each of the 3 occupant sizes, a resultant value representing an "average"-sized occupant was determined, and those are the values shown in Figures 1 and 2.

Human Tolerance to Deceleration

As the peak decelerations increase, the likelihood of an occupant surviving the blow decreases. The relation between the deceleration measures and the likelihood of survival is shown in Figure 3. The relation is based on extensive impact tolerance research conducted at the University of Michigan Highway Safety Research Institute (HSRI) and elsewhere and is appropriate for deceleration pulse durations at the indicated level of longer than 20 milliseconds. The head impact tolerance curve was developed at HSRI itself, while the HSRI representatives concurred with the chest tolerance curve following its development at Ford Motor Company.

Combining the impact tolerance relation shown in Figure 3 with the decelerations shown in Figures 1 and 2 allows the life-saving potential of each restraint system to be assessed. For example, a driver using the harness system will sustain, in a 40-mph barrier-equivalent crash, a peak deceleration of about 95 head g's (Fig. 1) and 58 chest g's (Fig. 2). These values are referred to the relation shown in Figure 3, and the lower of the 2 associated survival likelihoods, 0.75 in this case, is taken to represent the effectiveness factor in this situation.

Now that a method for assessing restraint-system effectiveness in each accident situation has been developed, the question becomes, How many fatalities occurred in that situation to start with? The source for determining the proportion of fatalities that occur in each accident situation was the 934 single-impact fatalities contained in the ACIR sample.

Two of the parameters used to characterize the accident situation, seated position and impact direction, are coded directly by ACIR. The third parameter, accident severity as measured by barrier-equivalent speed, was developed from an accident severity rating assigned to each case by the ACIR coders.

Barrier-Equivalent Speed Distribution

This severity level is coded by ACIR personnel on the basis of deformation and frame damage shown in vehicle photographs. The relation between severity and barrier-equivalent speed was established by a careful matching of reference photographs (used by the ACIR coding experts in determining the severity level) with photographs of crashes conducted by Ford Motor Company at known impact speeds. This matching allowed an estimation of a range of speeds into a fixed barrier producing about the same damage as shown in each reference photograph. Each reported severity rating was thus assigned an associated fixed-barrier speed.

Two minor adjustments were made in the speeds to obtain the final barrier-equivalent speed distribution. One of those adjustments was applied to each of the crashes in the sample to isolate the proportion of crash energy dissipated along the impact direction line, thus discounting the portion of energy associated with rotation or "spin-out." A second adjustment was made to the overall speed distribution to correct the rural bias of the ACIR data source. The cumulative effect of these 2 alterations was rather minor.

Figure 4 shows that the median barrier-equivalent speed for fatality vehicles in frontal collisions was less than 40 mph. This distribution concerns only vehicles in which a fatality occurred; if vehicles in lesser or no-injury accidents had been considered, the distribution would be shifted downward considerably.

Also shown in Figure 4 is an impact-speed distribution based on in-depth, or "clinical," accident investigations conducted under the sponsorship of the Automobile Manufacturers Association (AMA). Each of these rigorous investigations leads to a detailed report concerning a large number of accident-related vehicle and occupant parameters; about 800 such cases were contained in the data file. This file consists of investigations conducted by the Trauma Research Group at the University of California, Los Angeles, and by the accident investigation group at the University of Michigan. The distribution of barrier-equivalent speeds for the 42 fatality vehicles impacted from the front in the AMA in-depth file, along with the distribution based on the ACIR data, is shown in Figure 4. Although these AMA cases are inappropriate as source data for this paper because of their small number and the lack of appropriate sampling

Figure 1. Maximum head decelerations for various restraints.

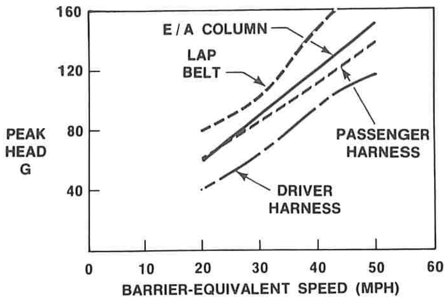

Figure 2. Maximum chest decelerations for various restraints.

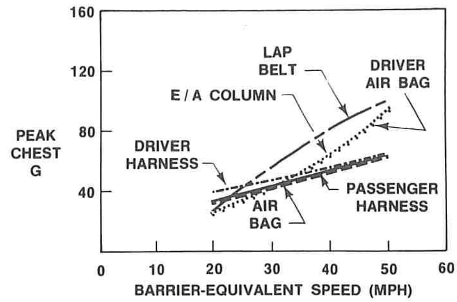

Figure 3. Probability of survival as a function of maximum deceleration.

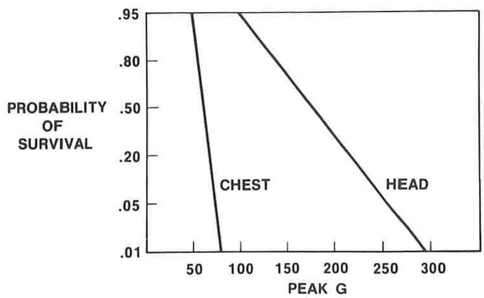

Figure 4. Barrier-equivalent speeds for single-impact frontal fatality vehicles.

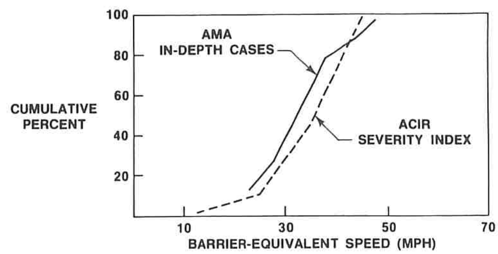

Table 1. Estimated passenger car occupant lives saved in 1969 with complete use of each safety system.

Restraint System	Non-Roll-Over Single Impact	Non-Roll-Over Multiple Impact	Roll-Over Without Collision	Roll-Over With Collision	Total
Shoulder harness for driver and right-front occupant and lap belts for all other occupants	11,700	2,300	6,500	1,100	21,600
Lap belt for all occupants	7,400	1,600	5,900	1,000	15,900
Air bag only for all occupants	9,700	900	200	100	10,900
Air bag with lap belt for all occupants	9,900	2,000	6,100	1,000	19,000

Figure 5. Lives saved as a function of active restraint system used.

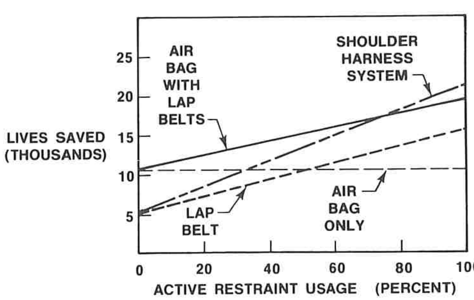

Table 2. Estimated baboon and human head-on crash survivability as a function of restraint system used.

Restraint System	Baboon Test LD-50 Speed[a] (mph)	Scaled Human LD-50 Speed[a] (mph)	Assumed Cumulative Crash Fatalities Saved With 100 Percent Usage of Restraint[b]: Percent	Lives/Year
Lap belt only	31	21	<10	<3,700
Lap and shoulder belt	45-57[c] (52)	30-38[c] (35)	27-70[c] (46)	10,000-26,000[c] (17,000)
Air bag and lap belt	59	40	74	27,500
Air bag only	>60[c]	>41	>76	>28,200

[a]LD-50 speed refers to the estimated barrier equivalent speed at which the deceleration experienced by the user of the given restraint system would be lethal to half of the healthy population.

[b]This assumes that LD-50 speed approximates the median fatal speed for the population. Savings are taken from Figure 4, ACIR curve.

[c]57 mph with elaborate Air Force double shoulder harness system [12]. Single diagonal belt is probably 10 to 20 percent less effective.

techniques in their collection, the close resemblance of the AMA and the ACIR distributions at least partially validates the severity-rating-based speed estimates used in this study.

Calculation of Single-Impact Effectiveness

Each single-impact fatality can be uniquely placed in an accident category, according to seated position by impact direction by barrier-equivalent speed. Knowing the distribution of real-world accident situations and the associated effectiveness provided by each occupant-restraint system, one can calculate the number of lives that would be saved by each restraint in each accident situation.

For example, consider all the driver fatalities that resulted from a 12 o'clock or direct (frontal) crash at a barrier-equivalent speed between 36 and 45 mph. The deceleration and human-tolerance formulations discussed earlier predict that, if all drivers used the shoulder-harness system, 75 percent of the fatalities would be eliminated. The distribution of ACIR fatalities places about 14 percent of all single-impact fatalities in the designated accident situation. The product of an effectiveness factor indicative of the fatalites eliminated (0.75 in this example) times the corresponding actual proportion of total fatalities (0.14 here) gives the proportion of the total existing fatalities that would be eliminated in the particular accident situation.

The sum of these proportional lives-saved estimates across the 3 accident situation variables (seated position, impact direction, and barrier-equivalent speed) yields the percentage of existing fatalities that would no longer occur as a result of usage of the given restraint system. For example, for 100 percent usage of the shoulder-harness system, these proportions sum to 0.49. This represents the proportional effectiveness of the present harness configuration and may be interpreted as indicating that 49 percent of the unrestrained occupants who lost their lives would have lived if all the occupants had availed themselves of the present harness arrangement. The procedure for determining single-impact life-saving effectiveness for each of the other restraint systems was the same as that outlined here, with a different table of effectiveness values for each system. For each restraint system, however, the actual fatality distribution based on current accident statistics remains unchanged.

Multiple-Impact Effectiveness

Each multiple impact consists, by definition, of an initial impact followed by one or more additional collisions; those ensuing crashes will collectively be termed the subsequent impact. The sample of multiple-impact fatalities can thus be divided into 1 portion consisting of occupants killed in the initial impact and 1 portion consisting of occupants killed in the subsequent impact. Because the restraint benefit will be different in each of these portions, and estimate of the relative portion of the total sample in each division must be obtained.

The source of information on the division of lethality consisted in part of the AMA in-depth data file, which was discussed earlier in connection with the barrier-equivalent speed validation. In addition, about 450 multidisciplinary accident investigations conducted by a number of groups under the sponsorship of the National Highway Traffic Safety Administration (NHTSA) were examined for relevant information. Those investigations are conducted in a manner similar to that described above for the AMA investigations. From these 2 sources, 30 multiple-impact fatality cases were discovered. The narrative account of each of the 30 cases was examined to determine which of the impacts, the initial or the subsequent, produced the fatal injury. It was found that 9 of the 30 fatalities (30 percent) resulted from the first impact, while the remaining 21 deaths (70 percent) were caused by the subsequent impact. These values, 30 and 70 percent, were thus taken to be the likelihoods of each impact, initial or subsequent, producing the fatality in a multiple-impact accident.

Initial-impact proportional effectiveness was determined in the same way as single-impact effectiveness. For the 30 percent portion of the multiple-impact fatalities assumed to occur in the first impact, no further calculation was made of effects from the following impacts. In fact, however, it is possible that the subsequent impact could also be of life-threatening severity.

The benefit assigned to restraint systems for those occupants killed in the subsequent collision depended on the positioning afforded by a lap belt. For those occupants whose restraint included a lap belt, the entire restraint was assumed to be fully operational in the subsequent impact. It was presumed that the lap belt would retain the occupant reasonably in place through the initial impact and hence allow the complete restraint to perform its designed function. The actual proportional effectiveness was thus calculated exactly as if that impact had occurred first.

It was assumed that completely passive air-bag systems would furnish no subsequent-impact protection at all. The reason is that air bags rapidly deflate upon occupant loading, a necessity for appropriate energy absorption. Therefore, a functioning air bag would not be available for subsequent impacts. Even if the bag did not inflate in the initial impact, the unbelted occupant would tend to be severely displaced in that impact and would be poorly positioned to receive any benefit in the subsequent impact.

Roll-over Effectiveness

Saving lives in automobile roll-overs is dependent on reducing the incidence of ejection and its associated high risk of fatality. A certain proportion of the occupants of overturned passenger cars are killed, whether or not they are ejected. If an occupant is ejected, however, his risk of fatality increases significantly.

The consequences of roll-over involvement for the 1,486 principal-roll-over and 362 collision-roll-over occupants found in the ACIR data file are as follows:

Category	Number	Percent
Principal roll-over	1,486	
Not ejected	1,031	69.4
Not fatal	1,017	98.6
Fatal	14	1.4
Ejected	455	30.6
Not fatal	373	82.0
Fatal	82	18.0
Collision roll-over	362	
Not ejected	281	77.6
Not fatal	258	91.8
Fatal	23	8.2
Ejected	81	22.4
Not fatal	55	67.9
Fatal	26	32.1

Only occupants of 1964 model year or later cars were selected for this sample. These figures indicate that 30.6 percent of the principal-roll-over occupants and 22.4 percent of the collision-roll-over occupants are ejected. They also show that 1.4 percent of the nonejected occupants of principal roll-overs were killed, while 18.0 percent of the ejectees were killed. For collision roll-overs, 8.2 percent of the nonejected and 32.1 percent of the ejected occupants were killed. It is clear from these data that being ejected from the vehicle increases considerably the likelihood of being killed.

It was assumed that, whatever the restraint in question, the risk of fatality for each ejection condition was the same as that indicated in the preceding data. This means, for example, that in a principal roll-over accident an ejected occupant was killed 18 percent of the time and a nonejected occupant was killed 1.4 percent of the time, no matter which restraint was used, if any.

What differentiated the restraint systems was the proportion of occupants who were ejected. It was assumed on the basis of a Cornell Aeronautical Laboratory study (2) that a lap belt reduced the ejection probability to about 3 percent and that a shoulder harness essentially precluded ejection completely. On the other hand, an air bag all by itself had a very negligible effect (a 1 percent reduction) on the proportion of occupants ejected. Adjusting this ratio of occupants ejected to those not ejected from the

values for unrestrained occupants allowed us to estimate a number of lives saved that would result from use of each of the occupant restraint systems in roll-over crashes.

Actual Restraint Usage Adjustment

Some modification in the number of passenger car fatalities given earlier must be made before these data can be used as a basis for estimating an actual number of lives saved. These adjustments are necessary because the ACIR impact type of distribution, as well as the effectiveness measures for each type, assumes that each occupant is unrestrained; this does not describe the 1969 situation. Restraint-system usage in the total car population in 1969 was taken to be 30 percent lap-belt usage, plus 1 percent shoulder-harness usage. Using the effectiveness-calculation procedures described above, it was determined that 41,700 passenger car occupants would have been killed in 1969 if no one had used restraints. The difference between this number and the actual number of 37,100 given earlier represents lives saved in 1969 by existing restraint usage.

RESULTS

Table 1 gives the lives saved by the restraint systems considered in this study, assuming that all cars are so equipped and that there is complete usage of active restraints in those configurations where they are provided.

The current production harness system (lap belts for all occupants and harness for driver and right-front occupant), if it had been installed in all vehicles and been universally used, would have saved 21,000 lives in 1969. Most of the savings is in the single-impact category, where most of the fatalities themselves occur. A substantial saving of lives is found in the roll-over categories, however.

Usage by all passenger car occupants of the lap-belt-only system in 1969 would have saved 15,900 lives. Lap belts by themselves are nearly as effective as the harness system in preventing roll-over fatalities. In the non-roll-over situation, however, a large difference in benefit is found between lap-belted occupants with and without harnesses.

Universal installation of the air-bag system, with no usage of the available lap belts (a completely passive arrangement), would have saved 10,900 lives in 1969. Although the non-roll-over performance of this system is quite good (better than the lap belt alone, for example), the roll-over savings are negligible. Utilization of the lap belts in this air-bag system, while not affecting non-roll-over performance appreciably, has a large roll-over benefit, and thus increases the total savings substantially to 19,000 lives.

Figure 5 shows the lives saved for a number of restraint systems as a function of the percentage of occupants using the system. With no restraint "usage," the air-bag system saves 10,900 lives. The intersection of the dashed lines drawn across the figure at this level of savings with the lines for the other restraint systems indicates the active restraint usage rate needed to equal this purely passive system in benefit. The 5,700 lives saved with no lap-belt or harness-system usage consists of drivers saved by the advanced steering column.

Figure 5 shows that lap-belt use of 51 percent would save as many lives as the air-bag system with no-belt usage (10,900 lives). A 32 percent usage rate of the harness system would produce equivalent savings. Greater usage of either active system would, of course, produce greater benefit.

With 68 percent usage of the shoulder-harness system, a few more than 16,000 lives would be saved. This same percentage of lap-belt use in cars furnished with the air-bag system (with the remaining 32 percent of the occupants protected by the air bag alone) produces corresponding savings. If the usage rate of the active components in each system is the same, and this rate is greater than 68 percent, more lives are saved with the harness than with the air-bag system.

In conclusion, it seems as though the shoulder-harness system could potentially save more lives than could the simulated air-bag system. The harness system is valuable, however, only if used. A passive-restraint system, such as the air-bag system, is assumed to be beneficial in many situations regardless of the actions of the occupants.

Either system, the harness or the air bag, requires the use of the lap belt to be fully effective.

It is estimated that at the present time in cars so equipped some 40 percent of the occupants avail themselves of their lap-belt protection but only 4 percent of the drivers use their shoulder harnesses. If suitable air bags were developed and were in all cars in the population today, more lives would be saved by them than would be saved with the current 40 percent lap-belt usage. However, no suitable air-bag system has yet been developed; therefore, no cars today are equipped with air bags, and their installation in the total car population is still many years away, at best. In contrast, most cars on the road today are equipped with lap belts and many with shoulder belts. Thus, it seems that some way of increasing belt usage would unquestionably be extremely beneficial in saving lives and would surely be the most cost-effective way of increasing substantially the number of lives saved.

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DISCUSSION

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One is required, in the study of many-faceted problems such as this one, to make some simplifying assumptions that stand or fall based on the judgment of the reader. Some of these assumptions deserve discussion.

Let us first examine the conclusion reached in the final sentence of the paper, which states that some way of increasing usage of active restraints would surely be more cost-effective than passive restraint systems but suggests neither how it would be accomplished nor what it would cost. The conclusion is unsupported. The magnitude of the task of increasing restraint-system usage is underestimated by the authors, who imply that the group composed of more than 60 percent of all car occupants who do not habitually wear belts can be induced to do so without appreciable cost. One very recent occupant motivation study concludes that only gradual, limited success will be seen (2). Reliable data on cost and effectiveness of systems designed to improve belt usage are not available. In the absence of specified alternatives and cost data, conclusions about the "most cost-effective" alternative are not justified.

USAGE

The 40 percent lap-belt usage figure is probably based on a very optimistic estimate by the National Safety Council and should be referenced. Actually, belt usage is highly variable with geography and other factors. Some estimates have been made based on interviews and questionnaires, but actual observations show lower usage. Many studies, some very recent ones, indicate an actual lap-belt usage below 20 percent (3, 4, 5). Further, among those who can be induced to wear the belt systems, many are unable to realize full benefits for they cannot (because of anatomy and belt design) or do not (because of personal preferences or ignorance) wear the belts properly. Belts can cause serious injury if improperly worn (6).

TOLERANCES

Another source that should be better referenced is the human tolerance data shown in Figure 3. The data and assumptions used in the preparation of this figure have not

yet been published in complete form. The data, based on extrapolation from experiments with rhesus monkeys and other small primates, are a pivotal part of the study and should certainly be available for public examination. The chest injury data are particularly suspect (7). [The head-impact curve shown in Figure 3 is based on an extrapolation from primate experiments. The chest curve was not produced by HSRI (7).]

EJECTION

In their discussion of ejection, the authors omitted the effect of recent automotive innovations that are certainly important. The ACIR data bank includes primarily vehicles produced before 1970. The authors have used only that portion of the data that deals with cars of model year 1960 or later. In 1968 new door locks were required on passenger vehicles, and in 1970 windshield retention requirements were introduced, reducing the probability of ejection (8, 9). Thus, the ejection fatality rates used in the study are not fully representative of the substantially improved ejection behavior of modern vehicles (10). (The CAL study shows a 70 percent reduction in door-opening frequency by late model cars.)

MODELING

The techniques used for modeling the restraint systems should also be compared. Whereas the elaborate 11-deg-of-freedom Cornell Automobile Crash Victim Simulator was used for the belt systems, a simple, 1-deg model was assumed for the air-bag occupant. The improved distribution of force over the head and torso that is afforded by the air bag was thus ignored. Perhaps more important, both models ignored the effects of localized force on human tolerance. Both are purely kinematic analyses. The differences in method of application of deceleration forces cannot be overlooked: certainly the broad distribution of the air-bag forces will lead to smaller local pressures on the occupant and, consequently, to decreased likelihood of injury and fatality.

Several factors relating to the effectiveness of lap-belt-only restraints have not been made clear in the paper. Although the use of the lap belt alone can prevent total ejection and limit the range of interior targets that the occupant head and chest may strike, the head and upper torso are only grossly restrained. The lap-belt-only restraint causes the head and upper torso to rotate about the hip and can cause an increase in head tangential velocity. Eventually, the total momentum of the body must be removed by force impulses experienced in contact with vehicle interior surfaces. These force interactions are not easy to model. It is not clear from the paper how the upper torso of any modeled occupant, other than the driver, was brought to rest, i.e., cushion thickness, energy absorption, or windshield impacts.

A second belt-effectiveness factor that requires proper consideration in belt-restraint system performance is the effective slack in the belts. Slack may be allowed by a careless user, or it may be caused by seat softness and geometry. The presence of slack in the belt system can cause overshoot in the acceleration response of as much as 30 percent (11). What is probably more important, the presence of excess belt slack in an actual use situation can introduce fatal abdominal injury resulting from improper load transfer to the body. The actual seriousness of such abdominal injuries cannot be assessed by the peak acceleration terms used for the chest (Fig. 3).

MULTIPLE IMPACTS

The implication that passive restraints offer no protection for subsequent impacts deserves a more detailed analysis than was given in the paper. It is largely a matter of the relative severity and time phasing of the multiple impacts. Proper air-bag deployment and deflation characteristics allow satisfactory air-bag performance for most multiple-impact situations. Moreover, the effectivess of belt systems may also be expected to deteriorate in multiple impacts, particularly if one of the impacts is a side impact.

Although the lap belt does offer protection from ejection, the direct addition of lap belt and air-bag effectiveness as shown in Figure 5 is not justified. The lap belt-air

bag combination may actually cause more injury than the air bag alone in some crash modes, particularly if the belt is improperly worn.

AN EMPIRICAL APPROACH

As an alternative prediction of restraint performance and injury by mathematical models, one may take an empirical approach. Experimental determination of the lethal dose levels for primates can be combined with the ACIR statistical experience to give a realistic indication of relative effectiveness. A summary of this type of investigation is given in Table 2. Data relating to human tolerance have been derived by scaling the results of primate tests in situations designed to simulate various vehicle restraint crash environments. In the case of the lap-belt, lap-shoulder belt, and lap-belt plus air-bag systems, impact tests have determined approximate 50 percent lethal doses for baboons (12, 13). In the case of air-bag-only restraints, impacts of baboons at equivalent barrier speeds of more than 60 mph have not yet resulted in a fatality (13). Also, air-bag tests with human volunteers at barrier-equivalent speeds of more than 30 mph have not yet resulted in serious injury (11, 12, 14).

Table 2 gives distinctly different results from those given in the first column of Table 1 for 100 percent usage. The empirical technique predicts annual fatality reductions of 3,700, 17,000, 27,500, and 28,200 for lap-belt, lap-shoulder, lap-air bag, and air-bag-only systems respectively as compared to 7,400, 11,700, 9,900, and 9,700 for the same respective systems in the computer model approach. The picture of relative effectiveness shown in Figure 5 is thus significantly changed when the empirical approach is used.

SUMMARY

The paper has introduced an analytical approach to the comparative rating of automotive restraint systems. However, the employment of some questionable modeling assumptions and poorly substantiated biomechanical survivability data, together with very optimistic estimates of belt-system effectiveness and usage, siginificantly cloud the accuracy of the conclusions regarding relative effectiveness. The conclusion regarding cost-effectiveness is definitely not supported by any cost data contained in the paper and avoids the ultimate question of societal cost versus societal benefit. The true answer to this question requires more reliable data.

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AUTHORS' CLOSURE

COST EFFECTIVENESS

Methods other than general publicity campaigns are available to motivate usage of restraints. Results of an NHTSA study (15), concerning vehicles with systems that prevent the engine from starting if belts are not fastened, indicated that 95 percent of the sample surveyed kept lap belts fastened while in such cars. A study sponsored by Ford (16) showed that 72 percent of a sample of habitual nonusers of belts became consistent users when exposed to a system incorporating warning devices to remind occupants to fasten their belts. Furthermore, legislation in Victoria, Australia, requiring restraint usage has substantially increased usage rate in that state (17). Thus, it appears possible to raise belt-usage rates to very high levels by technological or legislative means. Yet harness systems incorporating advancements such as suggested here have been estimated (18) to be much less costly than air-bag systems. Therefore, belt systems are estimated to be 6 times as cost effective as air bags.

BELT-USAGE RATES

Warner is quite correct in noting that belt usage is highly variable in different situations and that observational studies tend to be more reliable than interviews. Observations do not always lead to low-usage estimates, however. For example, a recent observational study (19) conducted by the Highway Safety Research Center of the University of North Carolina found a 1968 usage rate of 36 percent, much closer to our 40 percent than to the less than 20 percent proposed by Warner.

BELT-INDUCED INJURY

Twenty-six documents in the general references of NHTSA Docket 69-7 reported on accidents involving belt-restrained occupants of passenger cars. Of the 3,438 such occupants, only 67 (2 percent) sustained some degree of injury directly attributable to the belt-restraint system. No statistics are yet available for potential air bag-induced human injuries in vehicles; only air bag-baboon injuries have been reported for tests conducted at Holloman Air Force Base (discussed below).

HUMAN TOLERANCE

As mentioned in the text, the primary source of the tolerance to impact relations, which are indeed of central importance, was the Highway Safety Research Institute. Using data obtained for the most part from their own experiments (20) the HSRI personnel developed and furnished to Ford 2 curves showing the expected relation between probability of survival and peak triangular pulse head acceleration for both frontal and lateral head impacts. Human tolerance to chest impact was also determined as a function of peak triangular pulse chest acceleration. A properly restrained adult male should be capable of tolerating 30 to 45 g anterior-posterior acceleration without serious injury (21, 22); at the other extreme, we would expect very few to survive at more than 80 g. Assuming that there is a normal distribution of tolerance between these limits results in the postulated relation between lethality and peak chest acceleration shown in Figure 5 of our study.

EJECTION

As stated in the paper, the sample used for determining ejection and fatality rates for occupants of roll-overs included only vehicles of model year 1964 (not 1960) or later. This date was chosen in an effort to have the sample be representative of on-the-road condition in 1969, the base year considered.

EFFECTIVENESS ADDITION

Warner is correct in asserting that "direct addition of lap belt and air-bag effectiveness as shown in Figure 5 is not justified." It is an important point that the air

bag-lap belt system requires separate analysis, and each curve shown in Figure 5 does in fact represent an individual calculation of lives saved through total system operation, not simply additive effectiveness.

AIR BAG-BABOON INJURIES

Specific baboon autopsy information pertaining to the test series at Holloman Air Force Base (13) may be found in general reference 7 of Docket 69-7 in 2 parts: "Baboon Lethal Tolerance Tests," June 1970, and DOT final report attachment to a letter from Robert Carter to the Office of Science and Technology, July 12, 1971. "Fatality" in this test series was defined as death within 3 hours following the test, and none of the 8 baboons subjected to crash tests using air bags alone died within the time period. However, all 8 animals were damaged, sustaining such injuries as aneurysm of the aorta at the abdominal bifurcation with an overlying thrombus, premaxillary fracture of the face, brain and spinal cord hemorrhaging, and rib fractures. In fact, one of the baboons was found dead in its cage the day following the test. How many of the remaining animals would have died from their injuries within a reasonable period (36 hours, say) is not known, for all save the one found dead were sacrificed within 24 hours of the test.

EMPIRICAL APPROACH

The unrealistic definition of fatality and the premature sacrifice of test animals precludes a meaningful comparison among the LD-50 speed estimates given by Warner in Table 2. Furthermore, as detailed in an affidavit submitted to Docket 69-7 by R. H. Fredericks on August 6, 1971, the Holloman baboon tests cannot be considered representative of the real-world crash situation because of certain characteristics of the air-bag system and crush distances that were employed. The unrealistic conditions specified at Holloman included an actuation time (20 ms) much shorter than that experienced in actual barrier crashes that use present technology (35 to 40 ms) and a bag volume of 7 ft^3. This bag volume scales to an equivalent bag size of 21 ft^3 for a human, which would be impossible to package in an automobile. The Holloman tests also employed a bag finely tuned to reduce injury at the specific conditions of these tests.

The comparisons given in Table 2 are also questionable because the speeds were calculated from an accelerometer mounted not on the occupant but on the sled; in addition, the sled was decelerated in only 2 ft, whereas an automobile exhibits crush proportional to impact velocity. Hence, the deceleration forces experienced by the baboons during the tests cannot be related to—but no doubt were much greater than—what would occur in an actual automobile. The Holloman report also indicates that the cause of some of the lap-belted baboon fatalities was head-neck trauma. Some of the primates' heads contacted the floor during deceleration, an impossible result in a lap-belted car occupant!

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SHOCK INDEX CLASSIFICATION FOR HIGHWAY VEHICLES

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A program, jointly sponsored and promoted by the Army, Navy, Air Force, and Marine Corps, has produced a shock index classification for highway vehicles. The index is an empirical relation among the static mechanical characteristics of the vehicle and the low frequency shocks transmitted to the cargo. It is relatively simple and intended to be a user guide for shock transmitted to the cargo during transportation. This paper gives the formulas and methodology for obtaining the index. The first planned use is for traffic managers to effect a rough balance in service between the vehicle cushioning and cargo fragility. Cargoes whose loss costs are small compared to added vehicle-cushioning costs will also be balanced for optimum economics when the index ratings are known. A comprehensive program will extend the same concept to all modes. Also shock indexes or similar empirical factors will be developed for classifying highway pavements with regard to shocks transmitted by various highway pavements.

•MODERN shipment of cargo by intermodal containers has forced transportation personnel for all modes to know more about damage-producing shocks and vibrations and to become better organized to control them. Improvements or classifications are required across the board for total system improvement. There is an absence of definitive information regarding damage-causing shocks transmitted to cargo during transit. Loss and damage are not known to be significantly higher for highway shipments than for shipments by other modes of transportation. Perhaps this is the reason why more effort has not been expended to study, analyze, and control highway shocks.

Three principal areas of utilization compel the military to pursue control of highway shocks. The first is that highway transport for connector hauls and to terminals and ports for transshipment is extensive. The second is the high priority for improving the shock attenuation to shipments of hazardous, fragile, and key items or military materiel. The third is the increase in intermodal containerized shipments.

There has been a marked increase in the number of military cargoes where better than average ride for highway shipping would substantially improve the basic system reliability. When improved cargo reliability or improved cargo ride is sought, more study, analysis, and action addressed toward highway shock control are essential.

For intermodal shipments, the highway shock environment is an interacting portion of the total transportation shock environment. This interrelation was emphasized during a recent shipment of containerized ammunition. The cargo was restrained at the ammunition manufacturing plant to resist shocks for all modes. Consequent to highway shipment from the plant to the ocean port, normal vertical shocks caused damage to the vertical cargo restraint members. The restraint parts damaged were required to restrain the cargo during the ocean portion of the shipment and had to be replaced or repaired in advance of the ocean shipment. Vertical cargo restraints have to be designed to withstand highway shocks that are damaging not to the cargo but to restraint system components that work farther along the route. The desired procedure is to restrain one time for all modes so that rehandling and reinspection are minimized.

Sponsored by Committee on Vehicle Characteristics and Special Committee on International Cooperative Activities.

Frequently, in highway transportation a shipper can pay additional costs for improved cargo ride and yet receive the same or higher shocks transmitted to the cargo. This occurs because the relation among highway, highway vehicle, cargo mechanics, cargo restraint, and accumulative effect of other modes of transportation either has not been developed or has not been communicated in a practical procedure. Traffic managers order or specify generally the mode, the type of equipment, the route, and the cargo restraint. Packaging requirements are frequently set up independently. All of these factors affect the shocks transmitted to the cargo. Extra money spent to improve one factor may not affect the overall system and, in extreme cases, could even result in more transportation money being spent and the system being worsened.

Transportation research and development tend to hit on one or more interrelated areas and to result in component improvement that is not necessarily a system improvement. When system improvements are made, rarely does feedback to the improvers occur, mostly because there exist no performance terms that are common to research manufacturing and operations.

There is a most pressing need to expend the necessary effort to organize highway transportation ride-attributing characteristics into qualified terms that can be communicated practically and related properly to the total system. In this connection, a uniform system that references pavement roughness could provide a valuable index for predicting ride characteristics correlated with a shock and vibration "signature" of a system. During the past several years, the military transportability agents have addressed themselves to a ride signature.

The first 2 areas approached and discussed in this paper are shock classification of highway vehicles and cargo-restraint system classification. Considerable shock and vibration work has been conducted for particular cargo-vehicle combinations. The efforts here are geared to benefit the majority of military cargoes that are not in the category of those now receiving adequate attention. General cargo items will profit most from classification and organization.

An interdepartmental agreement was formed among the Army, Air Force, Navy, and Marine Corps to sponsor and pursue jointly programs designed to improve transportation with regard to shocks and vibrations to the cargo. A steering group was formed of one representative from each participating agency. Consequent to steering group meetings, the highway mode was selected for initial pursuit, and the concept of static measurements to predict dynamics performance for vehicle load configurations was established. A jointly sponsored procurement was let to General Testing, Inc., Springfield, Virginia, to develop a shock index (SI) equation based on actual static and dynamic measurements. An advisory group of representatives from National Bureau of Standards, National Academy of Sciences, Department of Transportation, National Aeronautics and Space Administration, and Aerospace Industries recommended that prior to release SI formulation be verified by a separate contractor. J. A. Johnson, Inc., Short Hills, New Jersey, was awarded the verification contract and has recently completed this work.

SHOCK INDEX

The SI formula was developed in a straightforward fashion. Because of the wealth of instrumented test runs, most of the important static vehicle characteristics contributing to the shock and vibration to the cargo were known. These include static spring rates, relative size of the truck trailer, percentage of the rated load, and cargo. Test runs were made with vehicles that had measured static characteristics and instruments affixed to measure the shocks transmitted to the cargo. The resulting data were then fitted mathematically to produce a formula that would express SI in terms of the measured static characteristics. The SI is a function of the severity of the accelerations transmitted to the cargo.

The SI range was set from 1.0 for the worst riding vehicle load configuration to 5.0 for the best. The SI values are a proportioned inversion of the acceleration readings to set higher values for better vehicles. Also the SI range was set to match with

present serviceability index (PSI) described by the Highway Research Board (1). The PSI also ranges from 1.0 for the worst road pavement to 5.0 for a near perfect pavement.

The results of the efforts described above have produced the following formula:

$$\mathrm{SI} = \left\{4.5\left[\frac{(A + B) - (C + D)}{A + B}\right]\left(0.5 + \frac{4K_L K_s + K_L^2 - K_s^2}{4K_L K_s + 4K_s^2}\right) - 0.53\right\}(\log \text{percentage of rated load} - 2.25) + \frac{(M + N)(P) + (S + T)(U)}{(F + G)(P) + (I + J)(U)} + 4.92$$

where

A = combined front weight, rated load at any position;
B = combined rear weight, rated load at same position as A;
$A + B$ = maximum rated gross weight;
C = combined front weight, no load;
D = combined rear weight, no load;
$(A + B) - (C + D)$ = maximum rated net weight;
K_L = greatest combined suspension spring rate, front or rear;
K_s = least combined suspension spring rate, front or rear;
F = combined front suspension deflection, rated load located forward;
G = combined front tire deflection, rated load located forward;
I = combined rear suspension deflection, rated load located rear;
J = combined rear tire deflection, rated load located rear;
M = combined front spring deflection, rated load at test position;
N = combined front tire deflection, rated load at test position;
P = combined front weight, rated load at test position;
S = combined rear suspension deflection, rated load at test position;
T = combined rear tire deflection, rated load at test position; and
U = combined rear weight, rated load at test position.

Figure 1 shows the spread of predicted versus actual values of accelerations transmitted to the cargo. Each point on the curve represents the maximum value for 1 test run used in the development of the curve. The goal was to keep the predicted values within a bandwidth of 1.0 SI for 95 percentile shock readings. The values shown for development tests represent all extreme loading configurations and the maximum acceleration reading. The results of these test runs and analysis indicated that maximum shocks are indeed responsive to changes in the static characteristics of the vehicle load configuration.

The basic plan for SI is to start with loose tolerance to see whether it has value and then to proceed to broader cargo coverage and more precision. The SI now applies to frequencies below 60 cycles per second, a 95 percentile shock acceleration, and a threshold on the acceleration count of 1.0 g. Also, SI is developed and based on extreme values for shocks. All factors, including the road surfaces, were selected to produce maximum readings. Typical cargoes will rarely have severe road conditions associated with speeds, weights, and mechanical combinations used for formula development. The severe shocks and factors causing them are what the SI will classify for control purposes.

Many other mechanical factors that do not appear in the SI formula contribute to shocks. The mathematical process of formulation eliminated factors whose contribution was outside the range of sensitivity of the SI. The highest contribution to the shock was the percentage of rated load factor. Figure 2 shows that for a typical standard truck the SI will range from 2.5 for 10 percent load to 4.8 for 100 percent load with all other factors remaining fixed.

It was deemed important to verify the formula by using it for actual vehicle cargo configurations and to check the predictions with instruments by making a test run over

public roads. A short public road test course consisting of a portion of Interstate highways, secondary roads, railroad crossings, and gravel roads was chosen for reproducible input. Eighteen vehicle load configurations covering different types of tractor-trailers, load placement, and cargo weights ranging from 10 percent rated load to maximum allowable load were selected to give reasonable coverage. All test runs were made at maximum legal speed. The data came within a 1.0 SI bandwidth for the more practical high load range and are judged useful for control of highway shocks to the cargo. Further formula improvement should draw all of the data within the 1.0 SI bandwidth. As part of the SI verification program, test runs were made over the same test course at speeds lower than the maximum legal speed. Reductions in acceleration with reduced speed are most pronounced and consistent with maximum loads.

The principal use for the SI is to improve communications among traffic management, packaging, design, and operations personnel. It is planned to use the term SI as the term "octane rating" is now used for gasoline. SI is not intended at this time to be precise, but it will fill a large void where no term or numerical factor is available to classify highway cargo vehicles with regard to their ride potential. Future plans call for extending the range of SI to cover a range of highway speeds, incremental load variations, lower threshold acceleration, higher frequencies, and a higher extreme value for significant accelerations.

An example of effective utilization of the SI concept is the development of a cargo-restraint system. Once the vehicle and the pavement have numerical classifications, the need for definitive and calculable cargo restraint is apparent. The 3 classifications need all be known to improve the predictability of the shocks transmitted to the cargo.

Intermodal considerations consequent to containerization have pressed for more definitive factors relative to shocks transmitted to the cargo during highway shipment. Highway transportation for containers is but one part of a larger intermodal transportation system. Shocks occurring during highway moves accumulate and add to the loss and damage figure for the entire shipment. Cargo is restrained in the containers one time for an intermodal shipment, and the method of restraint must be designed for the entire trip, which calls for design compromises for individual mode restraints. Many existing highway restraint systems are not rigid in the vertical direction because, during cargo bounce, the cargo returns to substantially the same spot. Rigid vertical restraint is required for other modes and needs to be strong enough to withstand highway verical accelerations.

The Military Traffic Management and Terminal Service (MTMTS) cargo-restraint system shown in Figure 3 was developed for use as in intermodal cargo restraint. The cargo is completely secured to the floor, which eliminates the uncertainties of end, door, side, and roof strength with regard to dynamic loads imposed by the cargo.

Of primary importance is the feature that the system is structurally simple and that the strength and margins of safety can be calculated with accuracy for individual cargoes.

Comprehensive transportability tests of the MILVAN container system fitted with cargo-restraint systems are in process of the U.S. Army Materiel Command Ammunition Center at Savanna, Illinois. The tests are organized into 6 separate phases as follows:

Phase	Method
Highway in service	C
Terminal handling	B
Rail	B
Highway	B
Terminal handling	A
Rail and highway	A

Method A tests are proof tests used to certify the system. Method B tests are failure tests where the load is increased to the point of structural failure to determine

Figure 1. Predicted SI versus recorded acceleration for 5 vehicles.

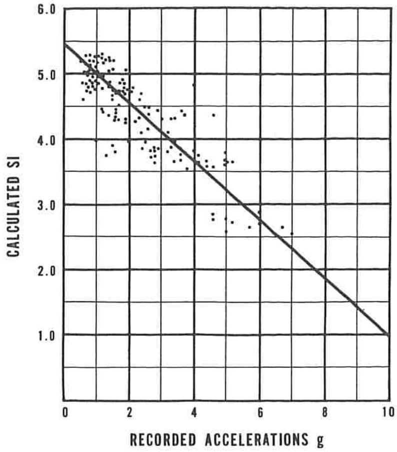


Figure 2. Effect of cargo weight.

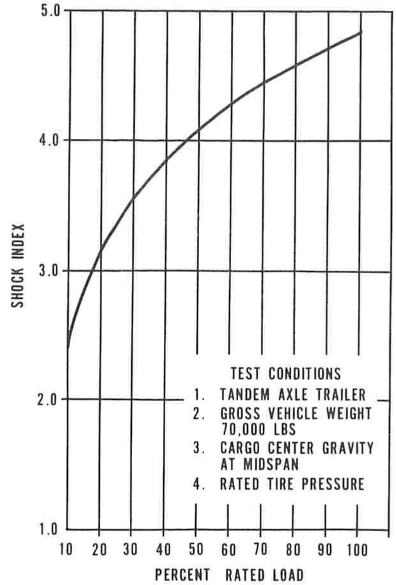


Figure 3. 105-mm ammunition secured with JK-1 cargo-restraint system in MILVAN container.

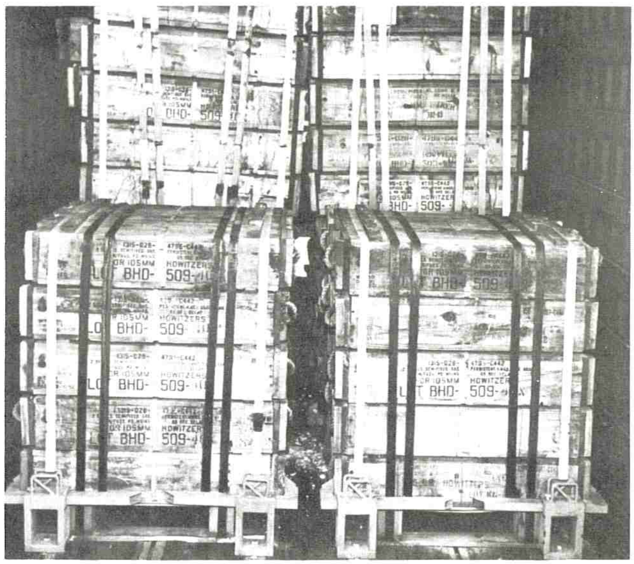
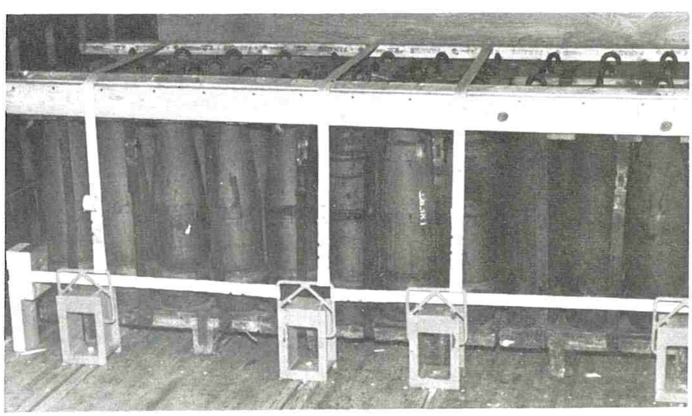


Figure 4. 155-mm ammunition secured with JK-2 cargo-restraint system in MILVAN container.



the failure loading and a margin of safety. Method C tests are instrumented tests of the cargo during actual shipment. The first 2 phases are complete, and the entire program is scheduled for completion in May 1972. Figure 3 shows 105-mm ammunition restrained in a MILVAN container with the JK-1 restraint system. Figure 4 shows the last row of 155-mm ammunition restrained in a MILVAN container with the JK-2 restraint system. The lateral restraint for JK-1 is built in the floor chock, whereas the lateral restraint for the JK-2 is accomplished with horizontal steel straps. When the test program is completed, failure loads and margins of safety will be developed for all components that are marginal for any of the complete assortment of transported shock and vibration loadings.

Preliminary analysis shows that the MTMTS cargo-restraint system is lighter, costs less, and is more predictable than systems now in use. It eliminates the need for lumber dunnage. Current blocking for ammunition requires approximately 800 to 1,800 lb of lumber per 8- by 8- by 20-ft container. This saving is more important from a natural resource conservation standpoint than it is from cost considerations.

The restraint system will give good reproducibility in strength performance, and that will tend to eliminate underdesign or overdesign. Its potential for numerical classification should help close the loop of numerical PSI's and SI's. The restraint system will prove most valuable for intermodal shipments where the cargo can be secured on time, based on the numerical strength classifications for all modes of transport and terminal handling provided.

CONCLUSIONS

A need exists to organize transportation systems for practical risk determination applicable to loss and damage consequent to transportation shocks and vibrations transmitted to the cargo. The 3 prime areas addressed are pavement conditions, vehicle suspensions, and cargo restraints. AASHO has made a good start with the concept of numerical classifications of pavements (PSI). The interdepartmental group appears to have numerical vehicle classification well started with the SI concept. MTMTS has shown one restraint system that can be numerically rated and that gives reasonably consistent and reproducible performance.

All concepts are general and broad and provide an opportunity for building comprehensive and practical organization of transportation shock and vibration control. Future areas to build include the development of interrelation among SI, PSI, and cargo restraint. All areas can be improved to include shock prediction for a more sophisticated range of cargoes. Expansion is also planned for more precise classification of all numerical factors with regard to speed, load variation, road types, automatic handling of cargo, and projection for research and development.

Standardization for pavement PSI and procedures for determining it require attention both nationally and internationally for the numerical values of the PSI to be complementary to the other rating factors. Effort is needed now to achieve standardization. Similar SI's are required for rail, sea, air, and terminal handling, and the interdepartmental group plans to arrange for and jointly sponsor development. This work affects industry, research associations, commercial operators, and the military. Cooperation, encouragement, and interest in this work are requested.

REFERENCE

1. The AASHO Road Test: Report 3—Traffic Operations and Pavement Maintenance. HRB Spec. Rept. 61C, 1962.

SAMPLING OF DRIVER OPINIONS TOWARD PERIODIC MOTOR VEHICLE INSPECTION

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A sampling of the opinions of motor vehicle operators was obtained to determine public attitudes toward several aspects of motor vehicle inspection. The survey was conducted in 3 cities while the operators were having their vehicles inspected at lane type of facilities. The inspection standards were similar in each of the cities; however, the periods of inspection vary. The results of this survey indicate that those who responded were overwhelmingly in favor of motor vehicle inspection. Areas of opposition appeared to be very minor.

•THE MOTOR vehicle laws of most states hold the owner responsible for maintaining his vehicle in a safe mechanical condition when operating it on public streets and highways. Although the term "safe mechanical condition" is ambiguous, in most cases the laws refer to a set of minimum safety specifications. In states that have periodic motor vehicle inspection (PMVI), these specifications are the inspection standards.

Although it focuses on the mechanical condition of the vehicle, PMVI becomes the means by which owners are forced to comply with the applicable standards. Public opposition to PMVI has developed because people generally have an aversion to being forced to meet this responsibility. Opponents of PMVI have expressed the view that this infringes too much on the vehicle owner's right to maintain and operate his vehicle as he sees fit. In addition, feeling has been expressed that requiring owners to have their vehicles inspected periodically causes undue hardship and inconvenience. On the other hand, proponents of PMVI indicate that a sound inspection program properly presented to the public can obtain and will retain their support.

Public support or its lack has been a critical factor in the success or failure of past PMVI programs. The record shows that successful PMVI programs generally have strong public support and that programs in some states have failed because of lack of support. In most cases, public support was absent because the information about the purpose and effect of PMVI was inadequate, the program was not presented to the public in an understandable manner, or the program did not have a workable set of standards and operating procedures. In some of the states that do not have PMVI programs, legislatures often have been reluctant to pass PMVI legislation because of the feared nonacceptance of the program by the public. A survey (1) of state motor vehicle administrators conducted to determine patterns of opposition to PMVI shows that those voicing public opposition are few. However, it is apparent that maximum public support must be obtained if an effective program is to be initiated in any particular state considering PMVI legislation.

Some opponents of PMVI contend that PMVI infringes too much on a vehicle owner's rights. Others feel that there is no firm proof that vehicle defects cause accidents or that inspection would help reduce accidents. Consequently, they conclude that PMVI would do nothing but provide increased business for repair shops and mechanics. The items of information requested in this survey were designed with these points in mind.

Some indication of the public's attitude toward PMVI was obtained in an opinion survey that was conducted as an adjunct to a study (2) of the influence of PMVI on mechan-

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Sponsored by Committee on Vehicle Inspection and Regulation.

ical condition. The survey obtained information from owners and drivers while they were having their vehicles inspected. Questions related to the respondent's personal characteristics and his attitudes toward vehicle maintenance, motor vehicle inspection, and highway safety. This report summarizes the survey findings.

METHOD

During 1967, a study was conceived and conducted (2) to determine the influence of PMVI on the mechanical condition of motor vehicles. For that study, the methodology adopted required that data be obtained from jurisdictions that have identical inspection facilities and standards but require different inspection intervals. A survey of existing PMVI programs disclosed that municipally operated inspection lanes conducted reasonably rigorous and consistent inspections and also provided superior opportunities for collecting data. Accordingly, data were collected for the mechanical condition study during the summer of 1967 in the cities of Ann Arbor, Michigan; Washington, D.C.; and Cincinnati, Ohio. [The inspection standards used in these 3 cities were based on the D7.1 Standard (3), and the inspection lane equipment being utilized was deemed to produce comparable data.]

Ann Arbor, Michigan, has no PMVI program, but at the time data were collected the Michigan random spot-check program had been in effect for 4 months. However, it was felt that for all practical purposes this had had little or no impact on the mechanical condition of vehicles. Data collected were at an inspection lane that was set up on a street. Passing vehicles were stopped by police and required to be inspected.

In Washington, D.C., vehicles have been inspected annually since 1939 at 2 inspection lanes owned and operated by the District of Columbia.

Since 1940, vehicles in Cincinnati, Ohio, have been required to be inspected twice each year at centrally located city-owned and -operated inspection lanes.

Concurrent with the mechanical condition study, a corollary survey was taken of owners and drivers to determine their attitudes on PMVI. A questionnaire was designed to deal with the areas of controversy surrounding the PMVI question. Responses were sought to the following 8 propositions:

1. PMVI is necessary,
2. PMVI keeps cars in safe condition,
3. PMVI causes unnecessary repair costs,
4. PMVI makes drivers more confident (of their cars),
5. PMVI makes drivers more safety conscious,
6. PMVI influences people to drive more carefully,
7. PMVI reduces accident rates, and
8. PMVI improves highway safety.

Because the conditions under which the vehicles being inspected were not uniform, 2 survey sheets were used; one was prepared for use in Cincinnati and Washington (Fig. 1) and another for use in Ann Arbor (Fig. 2). The items on the survey sheets were worded so that the responses concerning driver attitudes toward PMVI could be compared. These responses were subsequently transferred to punch cards to facilitate analysis of the data.

The occupational responses were coded according to the categories and income levels listed in tables published by the Department of Commerce (4) with incomes adjusted to 1967 levels. Occupations listed in these tables were divided into groups of male or female occupations, making it possible, in most cases, to determine the sex of the respondents in Cincinnati and Washington. This information on age, sex, occupation, income level, and vehicle was used to determine whether socioeconomic factors influenced attitudes toward PMVI, owner maintenance practices, and past vehicle inspection experience.

As vehicles arrived at the inspection stations, the drivers were solicited to voluntarily complete the survey questionnaire while they waited for their vehicles to be inspected. It was felt that this quasi-random sample would provide an adequate cross section of the population of each city surveyed. A survey sample of at least 500 responses was required in order to provide statistical significance at the 0.05 level of

confidence (5). A total of 2,375 responses were received: 536 from Ann Arbor, 1,119 from Washington, and 720 from Cincinnati.

ANALYSIS AND RESULTS

Utilizing the Automatic Interaction Detector program (6), we ran a statistical analysis to determine whether any specific characteristics of the sample populations correlated significantly with the respondent's attitude toward PMVI, vehicle maintenance practices, and history of previous rejections at inspection. The results proved inconclusive, and consequently this report is restricted to a straightforward presentation of the compiled responses.

As an adjunct to the presented data, profiles of the survey respondents in each city have been prepared. These profiles include information on sex, age, income, employment, and model year of car. The results are shown in Figures 3, 4 and 5; data are given in Table 1. For the Washington and Cincinnati data, where sex had to be established on the basis of the occupational descriptions given, a "no indication" category is included for cases in which it was not possible to determine the sex of the respondent.

The age data for Ann Arbor appear to be different from those for Washington and Cincinnati because the method of sampling in Ann Arbor tended to exclude working people who were at their places of employment and not on the road where they might be stopped for inspection. Inspections are a periodic requirement in Washington and Cincinnati, and employed drivers and owners bring their cars in to be inspected during lunch hour or after work. Inasmuch as the overall ratio of male to female respondents was 3.3:1 (Ann Arbor, 1.3:1; Washington, 5.2:1; and Cincinnati, 4.4:1), the age distribution for all respondents is similar to the age distribution within the male group.

The responses obtained with respect to the 8 previously stated propositions are given in Table 2. These results are very clear and, except for propositions 3 and 6, need no further explanation.

The responses to proposition 3 indicate the sampled opinions as to whether PMVI required the respondents to experience unnecessary repair costs just to pass inspection. The "probably" categories were provided for those who wanted to hedge on their replies. Examination of the responses disclosed that the "probably no" or "no" categories reflect sizable percentages. However, combining the "yes" and "probably yes" and the "no" and "probably no" responses revealed that the "no" categories overwhelmingly refuted an oft-stated objection to PMVI that owners incur unnecessary repair costs. These adjusted responses are given in Table 2.

Responses to proposition 6 indicated that public reaction to PMVI is quite divided as far as presuming that PMVI has an influence on driving habits. However, when the "yes" and "probably" responses were combined, the adjusted results, given in Table 2, indicated that the affirmative responses lead the negative.

To ascertain the attitudes of Michigan residents toward PMVI, we further analyzed the responses to the question, Do you favor a periodic motor vehicle inspection law in Michigan? (proposition 1). The respondents were requested to indicate whether they favored inspections conducted by state-licensed private garages or by state-operated inspection facilities and how often they thought inspections should be required. Of those favoring PMVI (492 out of 527 respondents), 64.4 percent favored state-operated inspections, 29.3 percent favored state-licensed garages, and 6.3 percent indicated no opinion. These same respondents indicated the following preferences as to the frequency of inspections:

Frequency	Percent
No opinion	1.0
Every 4 months	4.5
Every 6 months	32.7
Every 12 months	54.1
Every 18 months	2.8
Every 24 months	4.9
Every 36 months	0.0

Figure 1. Vehicle owner survey form used in Cincinnati and Washington.

As a research institution, we would like to know what kind of problems are important to automobile owners who are required to comply with Periodic Motor Vehicle Inspection laws. You can help us gain some insight into this important aspect of car ownership by answering the questions listed below. If you choose to contribute your knowledge and experience, please answer the questions as accurately as you can.

Please notice that you are not asked to sign this form. Your signature is not required.

1. What is your age?________________ Occupation?______________
2. What make and model year is your car?________________________
3. How many years have you had cars inspected?__________________
4. Has your car ever been rejected? Yes______ No________
   If yes, how many times?____________
5. Have you ever had the same car rejected two or more inspection periods in a row? Yes_______ No_________
6. Do you have somebody check your car over before you take it in for a required inspection? (Pick one answer)
   Always_________ Usually_______ Sometimes_______ Never________
7. When you find something wrong with your car, do you usually have it fixed: (Pick one answer)
   Within a day___ A week___ A month___ Just before an inspection____
   After an inspection____
8. Do you think that inspections cause you to spend money for repairs unnecessarily? (Pick one answer)
   Yes_____ Probably yes______ Probably no______ No_______
9. In your opinion, should car inspections be: (Pick one answer)
   More extensive_________ Continued as is_______ Less extensive_________
10. How would you rate the effects of required vehicle inspections for the following things?

People drive more carefully	Yes_____	Probably______	No______
Drivers are more confident	Yes_____	Probably______	No______
Reduces the accident rate	Yes_____	Probably______	No______
Improves highway safety	Yes_____	Probably______	No______
Makes people safety conscious	Yes_____	Probably______	No______
Keeps cars in safer condition	Yes_____	Probably______	No______
Inspections are necessary	Yes_____	Probably______	No______

11. How far did you drive to get here?_____________
    How long did it take?___________

If you wish to make any comment you may write on the back of this sheet.

Figure 2. Vehicle operator survey form used in Ann Arbor.

We would like to know what kind of problems are important to automobile owners who may some day be faced with compulsory motor vehicle inspection laws. You can help us gain some insight into this important aspect of car ownership. If you choose to contribute your knowledge and experience, please answer the questions listed below.

Please notice that you are not asked to sign this form. Your signature is not required.

1. What is your age?_____ Male☐ Female☐ Occupation?______________
2. What is the make, model and year of your car?_________________
3. How often do you take your car to a garage or service station specifically to get it "safety checked"?
   More than twice yearly☐ Twice yearly☐ Yearly☐ Never☐
4. How soon would you ordinarily have your car fixed if it should develop troubles like the following?

Repaired within a:	Week	Month	Longer
Brakes weak or "soft"	☐	☐	☐
Brakes pull right or left	☐	☐	☐
Front tires wear on one edge	☐	☐	☐
Car pulls right or left	☐	☐	☐
Turn signals don't work	☐	☐	☐
Headlights improperly aimed	☐	☐	☐

5. Do you favor a periodic vehicle inspection law in Michigan? Yes☐ No☐
6. Should compulsory vehicle inspections be performed by:
   State licensed private garage☐ State operated facility☐
7. Should compulsory inspections be required every:
   4 mo.☐ 6 mo.☐ 12 mo.☐ 18 mo.☐ 24 mo.☐ 36 mo.☐
8. Do you think that compulsory inspections would cause you to spend money for repairs unnecessarily?
   Yes☐ Probably yes☐ Probably no☐ No☐
9. How do you think compulsory inspections would affect the following things?

	Yes	Probably	No
People would drive more carefully	☐	☐	☐
Drivers would be more confident	☐	☐	☐
Would reduce accident rate	☐	☐	☐
Would improve highway safety	☐	☐	☐
Would make people safety conscious	☐	☐	☐
Would keep cars in safer condition	☐	☐	☐

If you wish to make any comment, you may write on the back of this sheet.

Figure 3. Age distribution of respondents.

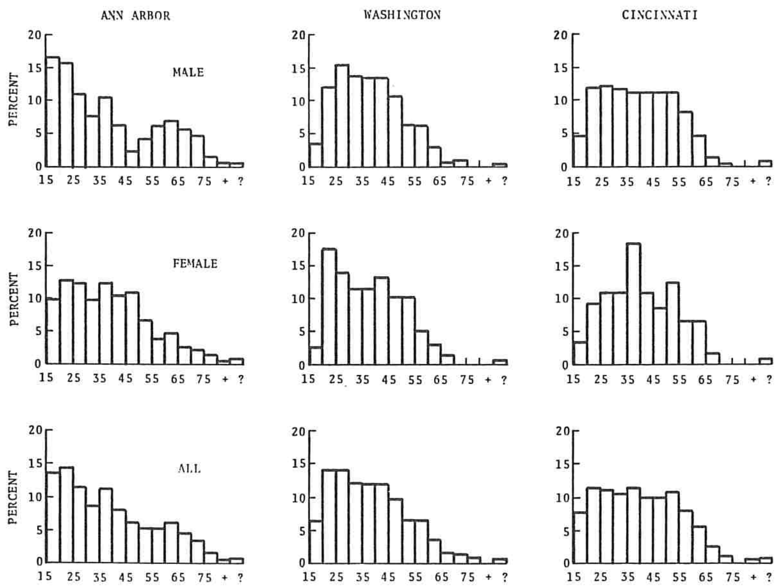

Figure 4. Income distribution of respondents.

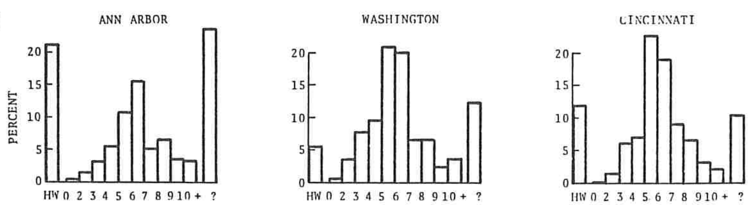

Figure 5. Age distribution of automobiles owned by respondents.

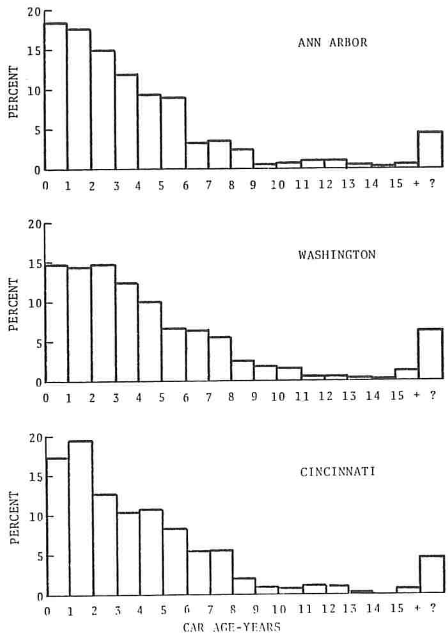

Table 1. Percentage of respondents in each employment status.

Status	Ann Arbor	Washington	Cincinnati
Housewife	21.1	5.5	12.0
Employed	54.5	82.3	77.9
Unemployed	0.7	0.6	0.1
Retired	8.2	3.6	4.3
Student	12.9	6.3	4.6
Unknown	2.6	1.7	1.1

Table 2. Percentage of responses to PMVI propositions.

Proposition	Response	Ann Arbor	Washington	Cincinnati
Is necessary	No opinion	1.7	11.0	7.2
	Yes	91.8	83.9	84.4
	Probably	—	3.7	6.5
	No	6.5	1.4	1.9
Keeps cars in safe condition	No opinion	2.2	8.5	7.5
	Yes	90.4	84.0	81.0
	Probably	6.3	6.9	10.1
	No	1.1	0.6	1.4
Causes unnecessary repair costs	Unadjusted			
	No opinion	1.1	2.4	1.2
	Yes	3.2	5.0	2.8
	Probably yes	11.2	9.4	2.9
	Probably no	46.6	18.9	20.6
	No	37.9	64.3	72.5
	Adjusted			
	No opinion	1.1	2.4	1.2
	Yes and probably yes	14.4	14.4	5.7
	No and probably no	84.5	83.2	93.1
Makes drivers more confident (of their cars)	No opinion	4.1	16.6	10.0
	Yes	54.3	50.7	54.7
	Probably	30.0	23.9	25.3
	No	11.6	8.8	10.0
Makes drivers more safety conscious	No opinion	3.3	15.5	11.7
	Yes	58.6	50.3	51.1
	Probably	29.5	22.1	23.2
	No	8.6	23.2	14.0
Influences people to drive more carefully	Unadjusted			
	No opinion	3.9	16.3	13.5
	Yes	29.8	27.6	25.0
	Probably	23.9	19.1	19.6
	No	42.4	37.0	41.9
	Adjusted			
	No opinion	3.9	16.3	13.5
	Yes and probably	53.7	46.7	44.6
	No	42.4	37.0	41.9
Reduces accident rates	No opinion	3.0	13.5	10.3
	Yes	65.5	59.2	55.1
	Probably	25.4	19.7	25.7
	No	6.1	7.6	8.9
Improves highway safety	No opinion	3.0	14.6	10.7
	Yes	72.8	66.7	64.3
	Probably	20.3	15.2	18.5
	No	3.9	3.5	6.5

These data indicate that the Ann Arbor respondents are strongly in favor of state-operated motor vehicle inspections conducted on an annual basis.

The relation of owner maintenance practices to attitudes toward PMVI was determined with responses to 2 questions (Fig. 1, questions 6 and 7) relating to pre-inspection checks and repair practices. The responses, given in Table 3, from Washington respondents regarding pre-inspection are spread rather uniformly, with the "sometimes" and "never" responses predominating. Most Cincinnati respondents, however, pointed out that they did not have their cars pre-inspected at a private garage. This response would indicate that the inspection lane is used to identify car defects. On the other hand, the responses regarding repairs show that the majority in both Washington and Cincinnati tend to have defects repaired within a week. Repairs must be made within 10 days in Washington, but in Cincinnati repairs are required within 30 days. In each case, only the defective items need to be reinspected. Failure to make repairs within the time limitation not only violates the ordinance, but also requires complete reinspection of the vehicle. Consequently, it is in the owner's interest to have the repairs made as expeditiously as possible.

The responses to the question of pre-inspection checkup and defect repair obtained in Washington and Cincinnati were tabulated only for male respondents (Table 4). Because the male is usually responsible for car maintenance, it was hypothesized that this tabulation would eliminate the effects of any lack of knowledge on the part of female respondents. Most male respondents have defects repaired on their cars within 1 week and a large number do so within 1 day. On the other hand, the "sometimes" and "never" responses regarding the pre-inspection checkup are nearly even for Washington, and responses from Cincinnati are much more numerous in the "never" category. This latter observation fortifies the conclusion reached by the field staff during the data collection phase that a large number of the drivers in Cincinnati utilize the inspection to determine what is wrong with their vehicles prior to having them repaired.

The survey data were also examined to determine the interaction between prior inspection experience, tendency to fix cars promptly, and attitudes toward PMVI. Table 5 gives the data for Washington and Cincinnati male respondents. The data show that most respondents have vehicle defects corrected within 1 week, most of those who are slowest in making repairs (longer than 1 week) feel that PMVI is necessary, and those who are most prompt with car repairs also have the highest percentage of previous rejections at inspection. It would appear that respondent attitudes toward the necessity of PMVI are not adversely affected by a past history of rejections at inspection. Neither are delays in having repairs made indicative of attitudes toward PMVI.

An examination was made of the premise that people in lower income groups have less favorable attitudes toward PMVI because they feel that PMVI causes them to spend money on unnecessary repairs. Only male responses were examined. Data given in Table 6 show that respondents with annual incomes of less than $5,000 constitute a small portion of the total; however, most of those in the lower income groups are in favor of PMVI and indicate that it does not cause them to make unnecessary repairs to their cars.

Each respondent was invided to make additional comments about PMVI. Of the total number of questionnaires returned, 242 contained additional remarks. Many of these did not pertain to PMVI but touched on varying aspects of highway safety and miscellaneous complaints about things such as driver licensing practices and law enforcement. An arbitrary categorization of these additional comments is given in Table 7. These results indicate that the majority of those making additional comments relating to PMVI were voicing approval suggesting improvements or alternatives or doing both.

CONCLUSIONS

Several conclusions can be drawn from this survey.

1. The public, as sampled in this survey, favors PMVI by an overwhelming margin. Further, the voluntary comments show that some of the dissenters disagree not with the need for some form of vehicle inspection but rather with the manner in which inspections are performed.

Table 3. Percentage of responses regarding maintenance and inspection practices.

Practice	Washington	Cincinnati
Pre-inspection checkup		
No opinion	2.7	1.8
Always	19.0	9.4
Usually	20.2	14.9
Sometimes	30.7	28.3
Never	27.4	45.6
Defects repaired		
No opinion	3.2	2.2
Within 1 day	32.4	29.3
Within 1 week	53.0	56.1
Within 1 month	6.5	8.8
Before inspection	2.8	1.7
After inspection	2.1	1.9

Table 4. Percentage of male responses regarding pre-inspection checkup versus defect repair time.

	Pre-Inspection Checkup					
Defects Repaired	No	Always	Usually	Sometimes	Never	Total
No opinion						
Washington	0.6	0.2	0.5	0.4	1.0	2.7
Cincinnati	0.9	0.2	0.0	0.4	0.6	2.1
Within 1 day						
Washington	0.5	9.5	7.0	7.5	8.7	33.2
Cincinnati	0.4	5.3	5.3	7.2	10.9	29.1
Within 1 week						
Washington	0.4	8.1	10.3	19.3	14.5	52.6
Cincinnati	0.2	4.4	8.2	17.0	28.2	58.0
Within 1 month						
Washington	0.0	1.4	1.2	2.7	1.6	6.9
Cincinnati	0.2	0.2	1.3	2.1	3.4	7.2
Before inspection						
Washington	0.2	0.5	0.4	0.8	0.6	2.5
Cincinnati	0.0	0.6	0.2	0.9	0.2	1.9
After inspection						
Washington	0.0	0.0	0.2	0.8	1.1	2.1
Cincinnati	0.0	0.0	0.2	0.0	1.5	1.7
Total						
Washington	1.7	19.7	19.6	31.5	27.5	100.0
Cincinnati	1.7	10.7	15.2	27.6	44.8	100.0

Table 5. Percentage of male responses regarding defect repair time versus PMVI attitude and previous rejection experience.

	PMVI Necessary					Previous Rejection			
Defects Repaired	No Opinion	Yes	Probably	No	Total	No Indication	Yes	No	Total
No indication									
Washington	1.1	1.2	0.4	0.0	2.7	0.2	1.0	1.5	2.7
Cincinnati	1.0	1.1	0.0	0.0	2.1	0.0	0.6	1.5	2.1
Within 1 day									
Washington	3.8	28.0	1.0	0.2	33.0	0.1	19.2	13.7	33.0
Cincinnati	2.6	24.6	1.3	0.6	29.1	0.2	18.6	10.3	29.1
Within 1 week									
Washington	4.6	49.1	1.6	0.4	52.7	0.0	34.5	18.2	52.7
Cincinnati	2.8	49.9	4.2	1.0	57.9	0.4	41.5	16.0	57.9
Within 1 month									
Washington	0.5	5.7	0.5	0.2	6.9	0.1	4.1	2.7	6.9
Cincinnati	0.4	5.9	0.6	0.4	7.3	0.0	5.2	2.1	7.3
Before inspection									
Washington	0.5	1.9	0.0	0.1	2.5	0.0	1.3	1.2	2.5
Cincinnati	0.0	1.3	0.4	0.2	1.9	0.0	1.5	0.4	1.9
After inspection									
Washington	0.4	1.5	0.1	0.2	2.2	0.0	1.5	0.7	2.2
Cincinnati	0.0	1.3	0.4	0.0	1.7	0.0	1.0	0.7	1.7
Total									
Washington	10.9	84.4	3.6	1.1	100.0	0.4	61.6	38.0	100.0
Cincinnati	6.8	84.1	6.9	2.2	100.1	0.6	68.4	31.0	100.0

Table 6. Percentage of male respondents in income groups and responses regarding PMVI attitude and repair costs.

	Ann Arbor			Washington			Cincinnati		
Income Level	Respondents	Favor PMVI	No Increased Costs	Respondents	Favor PMVI	No Increased Costs	Respondents	Favor PMVI	No Increased Costs
0-1,999	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2,000-2,999	1.6	0.6	1.3	3.2	2.4	1.5	1.5	1.3	1.1
3,000-3,999	1.3	1.3	1.3	7.0	5.5	2.9	6.9	5.5	4.0
4,000-4,999	3.6	3.3	3.0	7.6	5.5	3.4	5.9	4.6	3.6
5,000-5,999	14.1	13.1	10.8	27.8	24.2	16.9	30.7	25.0	20.8
6,000-6,999	18.6	16.7	14.1	27.2	22.8	14.9	26.1	22.6	17.5
7,000-7,999	7.8	6.5	7.5	9.1	8.0	6.7	12.4	9.9	6.1
8,000-8,999	10.5	10.5	8.8	9.2	8.7	6.3	9.3	9.0	6.5
9,000-9,999	5.9	5.9	5.2	3.3	2.9	1.8	4.4	4.0	3.1
Over 10,000	5.2	4.6	4.6	5.2	4.1	3.4	2.7	2.1	1.5
No indication	31.4	27.4	24.5	0.4	0.4	0.2	0.2	0.2	0.2
Total	100.0	89.9	81.4	100.0	84.5	58.0	100.0	84.2	64.4

Table 7. Percentage of respondents making comments on PMVI and nature of comments.

Item	Ann Arbor	Washington	Cincinnati
Respondents	10.3	9.6	11.1
Nature of comments			
Approve	43.6	26.2	30.0
Approve, suggest improvements	14.6	38.3	46.3
Approve, offer alternatives	20.0	18.7	10.0
Disapprove	1.8	1.9	3.7
Are critical, offer no alternatives	12.7	11.2	3.7
Are critical, offer alternatives	7.3	3.7	6.3

2. People who appear relatively slow to repair their cars or to correct defects detected at inspection do not object to PMVI. This finding refutes the premise that those people who tend to be lax in maintaining their cars would strongly object to having them inspected.
3. Respondents with a history of frequent or consecutive rejections of their vehicles at inspection do not appear to develop a negative attitude toward PMVI.
4. The majority of low-income respondents do not feel that PMVI causes them to spend money on unnecessary repairs.

In summary, this study indicates that a population conditioned to PMVI (as in Washington and Cincinnati) and a population without PMVI experience (as in Ann Arbor) both have favorable attitudes toward a PMVI program.

ACKNOWLEDGMENTS

The author gratefully acknowledges the assistance and cooperation provided by the following people and organizations: R. W. McCutcheon, Highway Safety Research Institute, for his part in the preparation of survey forms and participation in the analysis of data; W. J. Carlson, Highway Safety Research Institute, for his assistance in the early data analysis; Thomas J. Frey and his staff at the Cincinnati Inspection Lane Building; Wiley W. Godsey, District of Columbia Department of Motor Vehicles, and the inspection staffs at the Southwest and Northeast Inspection Stations; and Howard R. Zeck, Traffic Division of the Ann Arbor Police Department, and the officers assigned to the operation of the inspection lane in Ann Arbor.

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